THE MILITARY USES OF ASTRONOMY

F. C. MOLESWORTH

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THE MILITARY USES OF ASTRONOMY

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BY

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WITH A FOREWORD BY

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WITH DIAGRAMS

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FOREWORD

When I was at school and at Sandhurst very little was taught about astronomy and the phenomena of the universe. More is done now, and officers come into the Service having had some grounding in these matters. But it is not nearly enough that is given them, and this book by Major Molesworth will supply a great need.

The officers of the British Army spend much of their service in the empty places of the world, where there are no roads or sign-posts, and often no maps. If they can learn thoroughly what Major Molesworth has explained so clearly, and can apply the knowledge instinctively in the desert or bush, they may save the lives of their men, or make certain of the success of an operation.

It may be said that an officer can always obtain a guide who knows the way. But knowledge of direction will give an officer control of a bad or untrustworthy guide, and it is not necessary to emphasize the confidence that this knowledge can give.

I have met officers whose "bump of locality" is very poorly developed. Such officers may hope, by studying this book, to reach a "sense of the north" which some other lucky ones have as an instinct.

W. R. Birdwood,
General.
General Officer Commanding-in-Chief, Northern Command.

Murree,
October 25, 1923.

DEFINITIONS

Altitude. The angular distance of an object above the horizon.

Apogee. The point in the Moon's orbit furthest from the Earth.

Axis. The Earth's Axis is an imaginary straight line through the Earth's centre joining the Poles.

Azimuth. The true bearing of an object.

Bearing. True bearing, which is always implied when the expression " bearing " is used in this work, is the angle a straight line makes with the true north, measured from north round by east and south.

Celestial Equator. An imaginary line in the heavens midway between the celestial poles.

Conjunction—Inferior. A planet is said to be in inferior conjunction when exactly between the Earth and the Sun. Only Mercury and Venus can be in this position.

Conjunction—Superior. A planet is said to be in superior conjunction when the Sun, Earth and planet are in one line in that order.

Crescent. The term used to describe the shape of the lighted part of the Moon (as visible from the Earth) between New Moon and First Quarter.

Declination (*Dec.*). See para. 30.

Decrescent. The term used to describe the shape of the lighted part of the Moon (as visible from the Earth) between Last Quarter and New Moon.

Degree. The ninetieth part of a right angle.

Distance. See para. 20.

Ecliptic. The apparent path of the Sun in the sky; or, the plane containing the Sun and Earth.

Ellipse. The locus of a point the sum of whose distances

from two given points called the foci is constant. A circular disc seen obliquely is a good illustration.

Epoch. The time occupied by a planet between successive superior conjunctions.

Focus (plural *Foci*). See *Ellipse.*

Follow. A star is said to follow another when its R.A. is greater, *i. e.* it crosses the meridian later.

Gibbous. The term used to describe the appearance of the lighted part of the Moon (as visible from the Earth) between First and Last Quarter.

Greenwich mean time (*G.M.T.*). The time used in Great Britain and Ireland, taken from the local time of Greenwich.

Hypotenuse. The side of a right-angled triangle opposite the right angle.

Latitude (*terrestrial*). See para. 19.

Longitude (*terrestrial*). See para. 19.

Lunation. The period between successive New Moons.

Magnitude. A term used to describe the apparent brightness (not the size) of a star or planet.

Meridian. An imaginary line joining the celestial poles and passing through the zenith. An object on the meridian is therefore due north, due south, or overhead.

Minute (written ′). In angular measure the sixtieth part of a degree.

Node. A point of intersection of the orbit of a planet or satellite with the ecliptic.

Noon. The instant when the centre of the Sun's disc crosses the meridian.

Perigee. The point in the Moon's orbit when she is nearest the Earth.

Precede. A star is said to precede another when its R.A. is less, *i. e.* it crosses the meridian earlier.

Refraction. Distortion of rays of light by the atmosphere (or any other fluid).

Right Ascension (*R.A.*). See para. 31.

Satellite. A body moving round a planet; the Moon is a satellite of the Earth.

Solstice. The period of the year when the Sun reaches its greatest declination N. or S. (normally June 21 and December 21).

Summer Time. A method in use in certain countries of employing the longer daylight of summer by putting on the clock one hour on a certain date in spring and putting it back one hour on a certain date in autumn.

Tangent. (1) A straight line which touches but does not cut a curve.

(2) In a right-angled triangle ABC, of which B is the right angle, the ratio $\frac{CB}{AB}$ is called the tangent of the angle A (usually written tan A).

Tropic of Cancer. The parallel of latitude 23° 27′ N., marking on the Earth the point where the Sun is vertically overhead at the summer solstice.

Tropic of Capricorn. The parallel of latitude 23° 27′ S, marking on the Earth the point where the Sun is vertically overhead at the winter solstice.

Tropics. The portion of the Earth's surface between the Tropic of Cancer and that of Capricorn.

Wane, to. The term applied to progressive decrease in the Moon's phase between Full and New.

Wax, to. The term applied to progressive increase in the Moon's phase between New and Full.

Zenith. The point in the sky directly above an observer.

Zodiac. The series of constellations along the ecliptic.

Zone Standard Time. A method of reckoning time in certain zones (running N. and S.) from the local time of a meridian about the centre of the zones. The meridians taken are multiples of $7\frac{1}{2}$° E. or W. of Greenwich, so that the time in use in the zone differs from G.M.T. by an exact number of hours or half-hours.

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PLATE I. PRINCIPAL STARS IN THE N. HEMISPHERE
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PLATE II. PRINCIPAL STARS IN THE S. HEMISPHERE
Fold-out at end

THE MILITARY USES OF ASTRONOMY

CHAPTER I

INTRODUCTORY

1. The elementary facts of astronomy are matters of common knowledge; everyone, for instance, knows that the Earth turns round and that the Sun is the centre of a system which includes the Earth and other planets. Yet many well-educated people are ignorant of the apparent movements of the Moon and stars in the sky. The art of directing oneself by the stars, for example, although known centuries before the Christian era, is unknown nowadays except to a few who have studied the matter for themselves. It is the object of this work to describe such phenomena of astronomy as will be useful to the soldier, giving at the same time the reasons for such phenomena; since a fact with a reason is more likely to be remembered than a fact without a reason, while the reason remembered without the fact enables the fact to be recalled with little mental effort.

Summary of military uses of astronomy.

2. An elementary knowledge of astronomy may be made use of by the soldier in a variety of ways. For instance, the approximate time may be told by the direction of the Sun; conversely the Sun's bearing can be calculated if the correct time be known; it is possible to tell the time with fair accuracy from the positions of the stars; while marching by the stars is by no means difficult; anyone planning or taking part in night operations should know when the Moon will rise or set; and a knowledge of the tides is useful to those

engaged in landing operations or in operations near the sea coast. Besides these there are many other facts about astronomy easy to be learned and remembered which can be made use of by the soldier. This book is an attempt to set forth these uses in as simple a way as possible.

Necessity of observation.

3. First of all it must be understood that naked-eye astronomy is not an abstruse subject; it is, in fact, the astronomy which was known to and made use of by the Chaldeans and Greeks long before the Christian era. Astronomy, of course, has, like every other branch of science, its technical terms, which it is necessary to know, but in this work they are kept to a minimum consistent with clearness. Most of them are explained both where they occur first in the text and in the definitions at the beginning. Secondly, in astronomy as in many other subjects, an ounce of practice is worth a pound of precept. The best knowledge of the subject can only be obtained by constant observation of the heavenly bodies; but as few have the time and patience to carry out such observations, recourse to books on the subject is recommended as the next best plan; but the student is earnestly recommended to spend as much time in the open as he can in testing and verifying the facts laid down hereafter.

Surveying.

4. Although military operations are impossible without maps, and accurate maps cannot be made without surveying, which involves observations of the Sun and stars, yet surveying is not discussed in this book, since it is the business of a few specialists only in an army, and requires the use of instruments of some complexity and calculations for which some degree of mathematical skill is needed.

Apparent movements of the heavenly bodies.

5. It is convenient to begin with a description of the apparent movements of the heavenly bodies. A very simple experiment can be made to represent them. Suppose the observer is situated in London. Open an umbrella and, keeping the eye near the handle, direct the stem to the north, elevating it at the same time at an angle of about 51° with the horizontal. This means raising it rather more than half-way between the

horizontal and a point directly overhead. Now, keeping the stem of the umbrella directed to the same point, revolve the umbrella against the hands of the clock. Any point on the inside of the umbrella will now appear to describe a circle round the stem, in exactly the same way as a star appears to describe a circle round the North Pole of the heavens. Of course, one revolves the umbrella in a second or less, while the complete movement of the heavens takes a day. Also, for part of the revolution, the stars will be invisible owing to daylight. The stem of the umbrella is, roughly speaking, directed towards the North Pole of the heavens.

Now imagine that the substance of the umbrella is extended so as to form a complete sphere, while the observer is still able to keep his eye at the handle and revolve the sphere; imagine also that some opaque substance prevents that part of the sphere below the observer's eye from being seen. We now have a complete representation of the sky. The stars behave exactly as points on the inside of the sphere behave; such a point describes a circle, greater or less according to its distance from the stem of the umbrella, though in some cases the whole of the circle will not be visible, for the opaque substance we postulated will prevent it from being seen; similarly the stars describe circles round the North Pole of the heavens; such stars as are near enough to the North Pole are, apart from the effect of clouds and daylight, always visible; but the majority are visible for a portion only of their circles.

The reader is recommended to keep the umbrella illustration in mind whenever the apparent motion of the stars is referred to.

To illustrate this by a figure, suppose P in fig. 1 to represent the North Pole to an observer in the N. hemisphere, and A, B, C and D to represent various stars round the Pole. Suppose the stars to become visible at 1800 [1] and remain so until 0600, then the path of A during the night will be as shown.

[1] No apology is made for using the twenty-four-hours clock. Those not acquainted with it are directed to para. 67.

During the day, if it were visible, it would complete the circle as shown; and at 1800 hrs. on the following day would have reached its previous position. A second star, B, which is shown as being below the horizon at 1800, would rise about 1830 and be visible for the rest of the night. A third star, C, would set about midnight and rise just before dawn; while D represents a star close to the Pole, round which it describes a very small circle. The relative positions of the stars all this time, of course, remain the same.

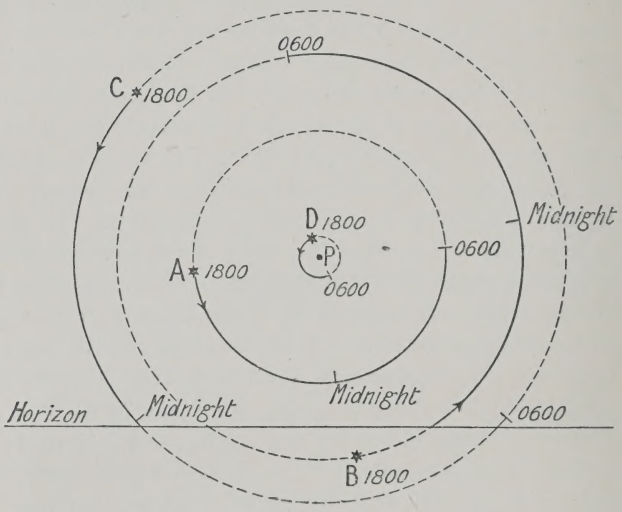


FIG. 1.

The Pole Star.

6. It is now necessary to explain how to find the North Pole in the sky. There is no star exactly at this point; but there is a fairly bright star quite close to it called the Pole Star, which for our present purposes we may take as being at the Pole. The way to find this star is as follows: take the two stars of the Great Bear known as the Pointers, and prolong the line joining them to about five times the distance between them (see fig. 2). The Great Bear is one of the easiest constellations to recognize (see para. 108).

Stars S. of observer (N. hemisphere).

7. Suppose now we turn in the opposite direction, we find the stars describing circles round the South Pole, which, of course, is invisible, being below the horizon; we therefore see stars describing parts only of their circles. A star, E (fig. 3), for instance, will be visible for only about six hours out of the twenty-four, and a star, F, for even less. It will happen at a certain season of the year that this time falls during the hours of daylight, so that we may not see a star for months together. A star will be at its highest point above the horizon when due south.[1]

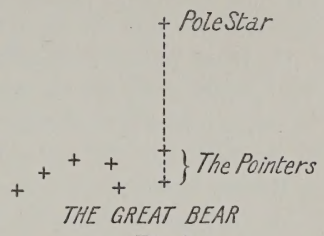


FIG. 2.

Stars near celestial equator.

8. At first sight, stars near the celestial equator[2] seem to obey different laws. This is not the case. They still move in circles, but as we are nearer the centre of the circle the effect to us is more like a hoop seen from a point near the centre. A star exactly on the celestial equator will rise due E. and set due W. in whatever part of the earth the observer is situated. A star N. of the celestial equator will rise N. of E. and set

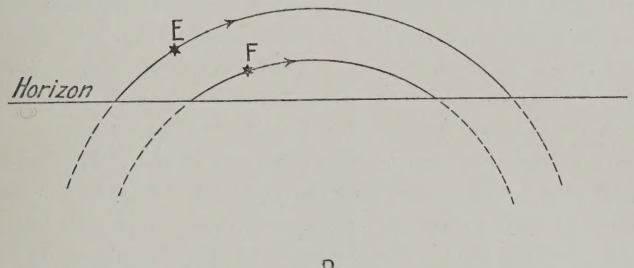


FIG. 3.

[1] Figs. 1 and 3 are applicable to both hemispheres. In the S. hemisphere fig. 3 would represent the northern sky and fig. 1 the southern; but the direction of motion of the stars would be reversed.

[2] The celestial equator is an imaginary line in the sky half-way between the two Poles.

N. of W., and a star S. of the celestial equator will rise S. of E. and set S. of W.

Motion of Sun, etc.

9. It is accurate enough for our present purpose to say that the Sun, Moon and planets perform daily apparent motions similar to those of the stars.

Appearance the same in the same latitude.

10. If the observer moves due E. or due W. from London the appearance of the heavens will remain exactly the same. The same stars will be visible at the same time of night wherever he is situated in the latitude of London, be it in Germany, in Russia, in Siberia or Canada.

Effect of moving north.

11. If, however, he moves N., the Pole Star will appear to rise. The further he moves north the higher it will rise, while the greater will be the number of stars which never set. At the Pole itself the Pole Star is nearly overhead, and all stars revolve at a constant elevation above the horizon.

Effect of moving south.

12. Moving S. from London, however, the Pole Star sinks. New stars appear towards the S., and those previously near the S. horizon get higher. At the equator the Pole Star is lost in the haze on the N. horizon, and every star, without exception, rises and sets. Continuing southwards, the South Pole rises above the horizon; but the traveller looks in vain for a conspicuous star to take the place of the Pole Star. A faint star, by name Sigma Octantis, is the nearest to the Pole. Round this the stars appear to revolve, but now with instead of against the clock. Continuing S. the phenomena we noticed in the N. hemisphere repeat themselves in the opposite order, until at the South Pole we find Sigma Octantis overhead.

Real and apparent movements.

13. Nothing is more interesting in the history of science than the story of how the real movements of the Sun, Earth and stars were deduced, step by step, from the apparent movements described above. The story would, however, hardly be relevant to our subject, and so we proceed to a brief description of such of the heavenly bodies as we wish to make use of for military purposes.

Solar System.

14. The Sun is the centre of the Solar System, by which is meant the collection of planets and their satellites, comets

and meteorites revolving round it. For the purposes of this work we are concerned only with the Sun, six planets (Mercury, Venus, the Earth, Mars, Jupiter and Saturn) and the Moon, which is a satellite of the Earth.

The mean distance from the Sun to the Earth is 92,830,000 miles; from the Sun to Saturn 880,000,000 miles.

The fixed stars.

15. At an immense distance from the Solar System are the so-called "fixed" stars; the distances of a few only have been measured, that of the nearest being about 25,000,000,000,000 miles.

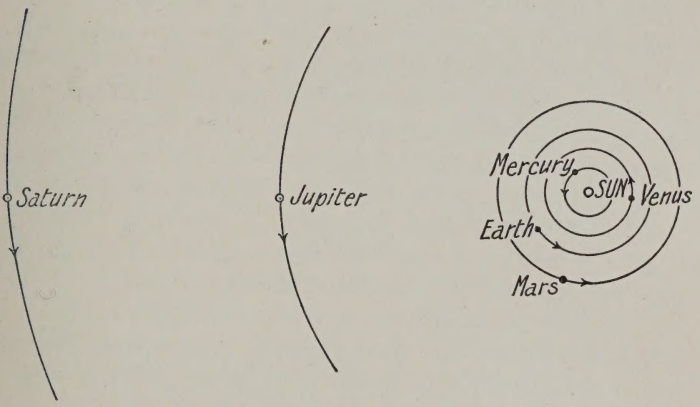


FIG. 4.

The Earth revolves round the Sun in a plane called the ecliptic. The larger planets deviate only very slightly from this plane. The stars visible to the naked eye are scattered pretty evenly in all directions throughout the heavens.

Plan of Solar System

16. The plan of the Solar System, as far as the six planets named above are concerned, is given in fig. 4. The distances of the planets from the Sun in the above figure are roughly to scale (about 270,000,000 miles to the inch). The following facts may be noticed :—

(*a*) All the planets move in elliptical orbits round the Sun; most of the ellipses are very nearly circles.

(*b*) They all move in the same direction, *i.e.* against the hands of the clock, assuming that one is looking from the north side (that is to say, above the plane of the paper).

(*c*) While Mercury takes only 88 days to revolve round the Sun, the Earth, as we know, takes a year, and Saturn 29½ years. The farther from the Sun, the longer the period of revolution.

(*d*) All these planets are, when conveniently situated with regard to the Earth and Sun, visible to the naked eye.

(*e*) They all shine by the reflected light of the Sun.

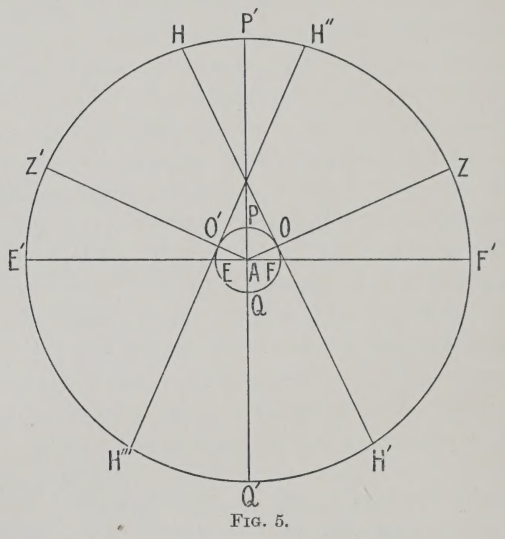


FIG. 5.

Distances of Stars.

17. The stars, as stated above, are at very great distances compared with those of the planets. On the same scale as is employed in fig. 4, the nearest fixed star would be at a distance of about 1½ miles. To complete the picture we must imagine the stars as lying not only in, but also above and below the plane of the paper.

Apparent movements of heavenly bodies.

18. Most of these facts are well known, but it is sometimes difficult for the beginner to reconcile them with the visible astronomical phenomena described earlier in the chapter,

such as the rising and setting of the Sun and stars. These are accounted for by the rotation of the Earth on its axis and the revolution of the Earth round the Sun. The former causes every celestial body—Sun, Moon, stars and planets—to describe a circle once a day round the Poles. The effect of the latter movement is described in Chapter IX.

In fig. 5 let PFQE represent the Earth. It is convenient in diagrams explaining the movements of the Earth to imagine the stars as projected on a circle concentric with that representing the Earth. So, let P′F′Q′E′ represent the firmament round the Earth. Take P as the N. Pole and Q as the S. Pole, EF the equator, A the centre of the Earth. The continuation of PQ both ways will meet the circle P′F′Q′E′ at P′ and Q′.

Let O be the position of an observer on the Earth's surface. The angle OAF is then the observer's latitude. If AO is produced to meet the outer circle at Z, Z is the observer's zenith.

At O draw a tangent to the circle PFQE, cutting the circle P′F′Q′E′ at H and H′. HOH′ is then the horizon of the observer at O; objects above this line will be visible from O and objects below it will be invisible. If the circle PFQE were infinitely small compared with the circle P′F′Q′E′, so as to represent more nearly the earth in comparison with the heavens, HOH′ would bisect the circle P′F′Q′E′. It can be seen then that at any place on the Earth the altitude of the elevated Pole is equal to the latitude of the place.

If the Earth did not rotate all the stars would occupy the same places continuously. As, however, the Earth turns round on its axis once in 24 hours, an effect is produced which we can follow by imagining the circle P′F′Q′E′ to be stationary, and the smaller circle PFQE to revolve inside it. In 12 hours its revolution will have carried O round to a point, similarly situated with regard to P, but on the other side of the circle. Let us call this point O′. Join AO′ and produce it to meet the outer circle at Z′. Draw H″OH‴ tangential to the inner circle, cutting the outer at H″ and H‴.

It will be seen at once that although the altitude of the Pole

remains the same, the new zenith and horizon are widely different. It can also be seen that to an observer at O, the stars between H and H″ round by P′ will always be visible, and those between H′ and H‴ round by Q′ will never be visible, while those between these limits will sometimes be visible and sometimes invisible; in other words, they will rise and set.

Latitude and Longitude.

19. As the appearance of the heavens differs according to the latitude, every officer should know the latitude of his station, and, for reasons which will be explained later on, it is also necessary that he should know his longitude.

We have defined the former above—latitude at any place is the angle subtended at the Earth's centre by the shortest line joining that place to the equator. Longitude needs a slightly longer explanation.

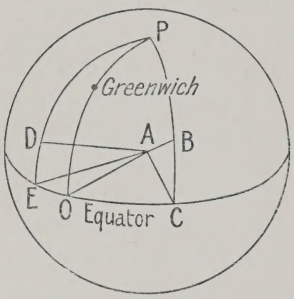


Fig. 6.

The line (technically called a "great circle") drawn on the Earth's surface between the Poles, passing through the Royal Observatory at Greenwich, is taken as a base. A point on this line is said to be in longitude 0°. This line cuts the equator at a point described as lat. 0°, long. 0°. Imagine now that one moves eastward along the equator until one reaches a point such that the distance traversed subtends an angle of 1° at the Earth's centre, the point is called lat. 0°, long. 1° E. An imaginary great circle joining the poles and this point is called the meridian of 1° E., and similarly for all other meridians. At 90° one has traversed a quarter and at 180° half the Earth's circumference. Meridians west of Greenwich, termed 1° W., etc., continue westwards until at 180° they meet those labelled E.

The above description is made easier by a figure (fig. 6). Let P represent the North Pole of the Earth, and PO the

meridian of 0° passing through Greenwich. PC and PE are two meridians passing through two points B and D. A is the Earth's centre. Then the angle BAC is the latitude of B and the angle OAC its longitude. The angle DAE is the latitude of D and the angle EAO its longitude. The longitude of B is east and that of D west of Greenwich. The angles shown in fig. 6 are, of course, foreshortened.

CHAPTER II

THE MEASUREMENT OF ANGLES

Angular distances.

20. At this point it is necessary to digress to discuss the measurement of angles. To those accustomed to Euclid's definition of an angle as " the inclination of two straight lines to one another," the statement that the apparent distance between two heavenly objects is measured in degrees causes some difficulty. But a knowledge of the actual distance, in cases where it could be given, would be useless. The angular

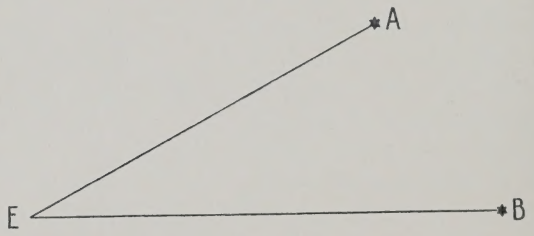


Fig. 7.

distance can be easily measured, and is all we ever want to know for military purposes.

Let A and B (fig. 7) be two heavenly bodies, and E the observer's position on the Earth; when we say that the angular distance between A and B is 10°, we mean that the angle AEB is 10°. Angular distance is frequently called simply " distance."

It is useless to try to estimate the distance in linear measure. The statement that, for instance, a certain star appears to be 10 feet distant from another is meaningless, because we do not know whether the 10 feet is taken at a distance of 100 yards, or 10 yards, or at arm's length from the observer.

21. A degree (written °) is the angle subtended by a chord of 1 unit at a distance of about 57 units; the units may be inches or hundreds of miles, but the relation remains the same. The distance from the horizon to the zenith—the point directly overhead—is obviously one right angle or 90°; and the whole circuit of the heavens, four right angles or 360°. Degrees.

22. A degree is divided into 60 minutes (written ′). A minute is therefore the angle subtended by a unit at a distance of 57 × 60 units = 3420 units. A halfpenny at a distance of about 95 yards, or a golf ball at 160 yards, subtend an angle of one minute. A minute is divided into 60 seconds (written ″), but we shall not have occasion to do more than mention this. Minutes.

23. On service one is usually unprovided with any means for measuring the distance between two heavenly bodies; but for military purposes extreme accuracy is unnecessary. The three following rules will be found useful. Rough means of measuring angular distances.

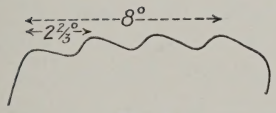


Fig. 8.

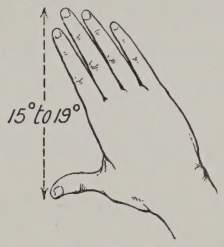


Fig. 9.

(*a*) If the arm be extended, the fist clenched and knuckles turned uppermost, the angle subtended at the eye by the distance between the first and fourth knuckles is in most persons about 8°; the second and third knuckles subdivide this angle into three of $2\frac{2}{3}°$ each (fig. 8).

(*b*) If the arm be extended and the thumb and second finger stretched out as far as possible, the angle subtended at the eye by a line joining their tips is in most persons 15° to 19° (fig. 9).

(*c*) The width of a pencil held at arm's length subtends an angle slightly greater than $\frac{1}{2}°$.

Clock method.

24. The clock method of describing the bearing of one object from another is well known to most soldiers, and may be described as follows. Assume one object, A, to be at the centre of the face of a clock whose twelve o'clock lies vertically over the centre; an object, B, to the right of A, such that BA makes an angle of 60° with the vertical is said to be at 2 o'clock; a third object, C, on a level with A to the left, is at 9 o'clock; one, D, vertically below, at 6 o'clock, and so forth (fig. 10). This method is very useful in describing roughly the position of stars in the sky.

Distance.

25. Both the apparent distance between two stars and the angle which the line joining them makes with the horizontal

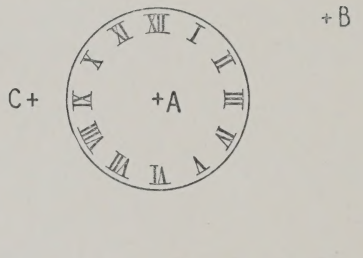


FIG. 10.

or any other direction are described in degrees, and it is necessary to distinguish carefully between them. Unless repugnant to the context the term distance when used in this work will mean the angle subtended at the eye by the distance between two objects.

Positions of stars.

26. The position of stars in the *Nautical Almanac* and in more commonly known works such as *Whitaker's Almanack* are given in terms of their right ascension and declination. The meaning of these terms is explained in Chapter III.

Construction of angles.

27. It is useful to be able to construct angles without protractor and compass, which may not be available on service. With paper, pencil and string multiples of 15° can be made, as

described in the "Manual of Field Works." For smaller angles the following is an approximate rule :—

Draw a line of length 57 units—say 5·7″—and at one end erect a perpendicular. Along this mark off a length of as many of the same units as there are degrees in the angle it is desired to make. Thus, to construct an angle of 7°, mark off ·7″. Join the point as found with the extremity of the original line, and these two lines will make the required angle. This is

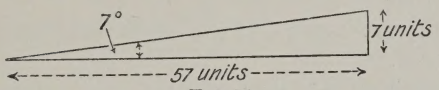


Fig. 11.

graphically shown in fig. 11. This method should not be used for angles above about 15°.

It is useful to remember that a watch forms a rough protractor, since each minute-division subtends an angle of 6° at the centre of the watch.

28. We shall have occasion to use the expression "the 'tangent' of an angle." Tangents.

In an angle ABC (fig. 12) draw DE perpendicular to BC. Whatever the length of the lines DE and BE, the ratio $\frac{DE}{BE}$ is

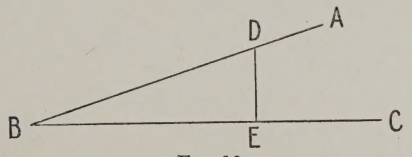


Fig. 12.

constant and is called the tangent of the angle ABC (tan ABC for short). A table of tangents is given in Appendix I.

Given one side AB of the right angled triangle and one angle CAB, the angle ABC being a right angle, the length of the side BC can be calculated, for $\frac{BC}{AB} = \tan CAB$.

Example.—The angle of elevation to the top of a steeple 1100 feet distant is 4°: required the height of the steeple.

Height = 1100 × tan 4° = 1100 × ·070 = 77 feet.

Tan 1° is, as we have seen (para. 27), approximately equal to $\frac{1}{57}$, and for small angles it is approximately true that the tangent of an angle is equal to the number of degrees in the angle divided by 57. Thus tan 10° differs from $\frac{10}{57}$ by less than 1%. The greater the angle, however, the greater becomes the proportional discrepancy. Thus tan 15° differs from $\frac{15}{57}$ by 1·8% of its value, and tan 20° from $\frac{20}{57}$ by 3·7%. For small angles, however, the rule is a useful one where great accuracy is not required.

The table given in Appendix I is one of natural tangents; most mathematical tables include "logarithmic tangents"; in using such tables care should be taken to refer to the correct table. Logarithmic tangents are nowhere used in calculations in this work.

An angle can be constructed given its natural tangent. Thus, to construct an angle of 7°, draw a straight line AB and erect a perpendicular BC, so that BC is equal to AB $\times$ tan 7° or ·123 times AB. Join CA. Then the angle CAB = 7°.

CHAPTER III

IDENTIFICATION OF STARS

Identification of stars.

29. In the succeeding chapters we shall frequently have to use the terms "right ascension" and "declination." In defining these it will be convenient to describe the method by which the stars and other heavenly bodies can be identified from a catalogue, such as those given in the *Nautical Almanac* or in *Whitaker's Almanack*. In these works lists of the stars are given by their right ascension (R.A.) measured in hours (h.), minutes (m.) and seconds (s.), and their declination (dec.) measured in degrees (°), minutes (′) and seconds (″). The R.A. and dec. of a star vary by a small amount, quite inappreciable for our purpose, throughout the year.

Declination.

30. The distance of a star from the celestial equator (generally abbreviated "dec.") measured along a N. and S. line, is its declination. It is necessary, in order to fix the position of a star, to know whether its dec. is N. or S. The dec. of a star on the equator is 0°, that of the N. Pole 90° N. and that of the S. Pole 90° S. N. dec. is usually written with a plus sign and S. dec. with a minus sign, thus — 5° 30′.

Right ascension.

31. The right ascension of a star is its distance measured in an easterly direction from an imaginary line joining the celestial poles through a point on the equator known as the "First point of Aries." The meaning of this term is explained in Chapter IX. This distance is measured, as already stated, in hours and subdivisions of an hour, the complete circuit of the sky representing 24 hours. For the same reason that degrees of longitude on the earth diminish from the equator to the poles, an "hour" varies from 15° at the celestial equator

to nothing at the poles. Stars on the 1 hour line cross the meridian an hour later than those on the 0 hour line. A star 1 hour W. of the 0 hour line is said to be in R.A. 23 h. This method of describing the position of a star is analogous to the employment of lat. and long. in Geography.[1]

The calculation of the distance between two stars whose R.A. and dec. are known involves some knowledge of spherical trigonometry; the approximate distance can, however, be easily measured off from a star chart.

To find the bearing and altitude of a star at a given moment, having given its R.A. and dec., also requires calculation. An approximate method is given in Chapter IX.

R.A. and dec. are used in defining the position of the Sun, Moon and planets. With these bodies they do not remain constant throughout the whole year, but vary appreciably from day to day and even from hour to hour.

Sun's R.A. and dec.

32. The table below shows the Sun's approximate R.A. and dec. for the first and sixteenth of every month in the year.

	R.A. h.	m.	dec. °		R.A. h.	m.	dec. °
Jan. 1	18	46	23 S.	July 1	6	39	23 N.
16	19	51	21 S.	16	7	40	21 N.
Feb. 1	20	58	17 S.	Aug. 1	8	44	18 N.
16	21	58	12 S.	16	9	42	14 N.
Mar. 1	22	48	8 S.	Sep. 1	10	40	8 N.
16	23	43	2 S.	16	11	34	3 N.
Apr. 1	0	41	4 N.	Oct. 1	12	28	3 S.
16	1	36	10 N.	16	13	24	9 S.
May 1	2	32	15 N.	Nov. 1	14	24	14 S.
16	3	31	19 N.	16	15	25	19 S.
June 1	4	35	22 N.	Dec. 1	16	28	22 S.
16	5	37	23 N.	16	17	34	23 S.

R.A. may vary by a few minutes from the values above, as Leap Year introduces a slight variation.

On intermediate dates the R.A. and dec. can be found by a simple calculation.

[1] Celestial latitude and longitude are quite different from terrestrial, and need not be considered in a treatise of this nature.

Example.—Required, the Sun's R.A. and dec. on Feb. 12.

	R.A.		dec.
	h.	m.	°
Feb. 1	20	58	17 S.
Feb. 16	21	58	12 S.
Difference for 15 days.	1	00	5
Difference for 11 days.			4
Therefore :			
Feb. 12	21	42	13 S.

CHAPTER IV

THE EARTH, CONSIDERED AS AN ASTRONOMICAL BODY

The Earth.

33. We have already seen that the Earth is a planet, the third in order from the Sun, from which it is distant about 92,830,000 miles. The orbit of the Earth round the Sun is an ellipse, differing only slightly from a circle; the Earth takes nearly $365\frac{1}{4}$ days to perform this orbit. The Sun lies at one of the foci of the ellipse. The Earth is nearest to the Sun (*i.e.* at one end of the major axis) on Jan. 1 and furthest away on July 4, the distances being 91,100,000 and 94,600,000 miles respectively. The radius vector, or line joining the Earth and the Sun, sweeps over equal areas in equal times. It follows that the Earth is moving quicker in January than in July. The Earth's equatorial diameter is 7927 miles.

The Earth rotates on its axis once in 24 hours; it is this motion that causes day and night.

The Earth's axis is inclined at about $23\frac{1}{2}°$ to the ecliptic; it is this inclination that gives us the seasons.

Altitude of Sun at noon.

34. At midwinter as the expression is used in the N. hemisphere (*i.e.* Dec. 21) the N. Pole is turned away from the Sun (*vide* fig. 13). As a result the whole of the Arctic zone, by which is meant the part of the Earth within $23\frac{1}{2}°$ of the N. Pole, is at this season in darkness for the whole of the 24 hours. At a point on the Arctic circle the Sun at noon will then just appear on the horizon. To an observer on the equator at noon the Sun will be $23\frac{1}{2}°$ from the zenith, or $66\frac{1}{2}°$ above the horizon. To an observer at $23\frac{1}{2}°$ S. lat., the Sun is vertically overhead at noon.

To an observer at the S. Pole, which is then in the middle of its 6 months' day, the Sun will be $23\frac{1}{2}°$ above the horizon.

In general the altitude of the Sun at noon at any point on the Earth's surface on Dec. 21 is, in N. latitudes, $90° - L - 23\frac{1}{2}°$ and in S. latitudes $90° - L + 23\frac{1}{2}°$ where L is the latitude of the place. With regard to the latter formula, it is necessary to omit the 90° for places between the equator and $23\frac{1}{2}°$ S.

At midsummer, *i.e.* June 21, these expressions are reversed. At noon the altitude of the Sun will be, in the N. hemisphere, $90° - L + 23\frac{1}{2}°$ (omitting 90° if necessary) and, in the S. hemisphere, $90° - L - 23\frac{1}{2}°$.

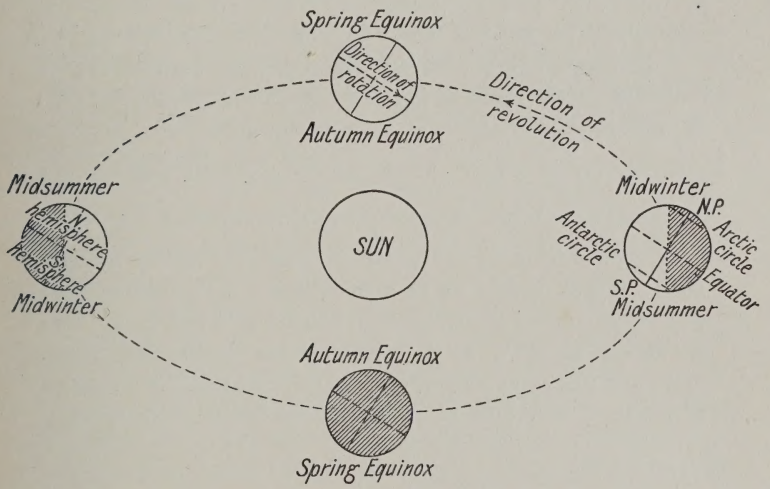


FIG. 13.

That part of the Earth's surface lying between $23\frac{1}{2}°$ N. and $23\frac{1}{2}°$ S. is known as the Tropics or Tropic Zone.

There are, as will be seen from fig. 13, two intermediate positions, called respectively the spring and autumn equinoxes, when the Earth's axis is directed neither towards nor away from the Sun. At these times day and night at every point on the Earth's surface are equal, and the altitude of the Sun at noon is exactly equal to 90° less the observer's latitude.

Geographical zones.

35. It will be seen, therefore, that the division of the globe into Arctic and Antarctic regions, Temperate and Tropic

zones, is not arbitrary, but has a definite relation to the position of the Sun with regard to the Earth's surface. At any place in the tropic zones the Sun is vertically overhead twice in the year. In the Arctic and Antarctic zones the Sun is below the horizon at noon at midwinter and above the horizon at midnight at midsummer. The Temperate zones are those intermediate between the Tropic and Arctic (or Antarctic) zones.

Distance of horizon.

36. It is often useful to know the distance of the horizon from a position at a known height. An approximate rule, good enough for all practical purposes, seeing that the distance is always affected to some extent by refraction, is as follows :—

Take the square root of the height of your position in feet and multiply the result by $\frac{7}{5}$. The answer will give the distance in miles to the horizon.

Example.—From a height of 4,000 feet what will be the distance of the horizon ?

$$\sqrt{4{,}000} = 63{\cdot}2. \quad \tfrac{7}{5} \times 63{\cdot}2 = 86{\cdot}5 \text{ miles.}$$

Shadow of Earth.

37. The shadow of the Earth is sometimes visible in clear skies; it can usually be seen for a short time before sunset as a dark band on the E. horizon, fringed with red, fading into the blue of the sky. As the Sun sinks the shadow rises, until, some minutes after sunset, it is lost in the growing darkness of the sky. A similar phenomenon can be seen at sunrise.

CHAPTER V

THE SUN

38. The Sun, the centre of the Solar System, is about 864,000 miles in diameter. Its mean distance from the Earth is 92,830,000 miles. Its angular measurement is consequently about 32′. It is commonly believed both in the case of the Sun and Moon that the angular measurement is greater at sunrise and sunset than at noon, but what little difference there is is the other way. The Sun.

39. From the law that when a ray of light impinges on a flat surface the angle of incidence is equal to the angle of reflection, it follows that when the Sun's rays strike an object, such as a heliograph, they diverge in a cone whose vertical angle is 32′. The tangent of this angle is about $\frac{1}{107}$, as stated in "Signal Training." At a distance of six miles the area covered by the reflected rays has a diameter of 50 yards. As that manual also states, this cone is actually bigger, the reason being that it is rare that a perfectly flat surface can be obtained, and any divergence from absolute flatness causes an increase of the angle of dispersion. As the Sun is in motion, the cone is constantly changing its position, necessitating frequent adjustment of the helio. Theoretically the light cone of a helio passes completely over a point in the same time that the Sun takes to move over its own diameter, *i.e.* a little over two minutes, for, as the Sun performs the entire circuit of the sky in twenty-four hours, it follows that its angular motion is 15° an hour or 15′ in a minute; it therefore moves over a space equal to its own diameter in just over two minutes. Light-cone of helio.

40. It is always useful to know the times of the Sun's rising and setting. These are given in almanacs, but only for a Times of sunrise and sunset.

particular spot on the Earth's surface. The times given in most English almanacs, for instance, are for Greenwich.

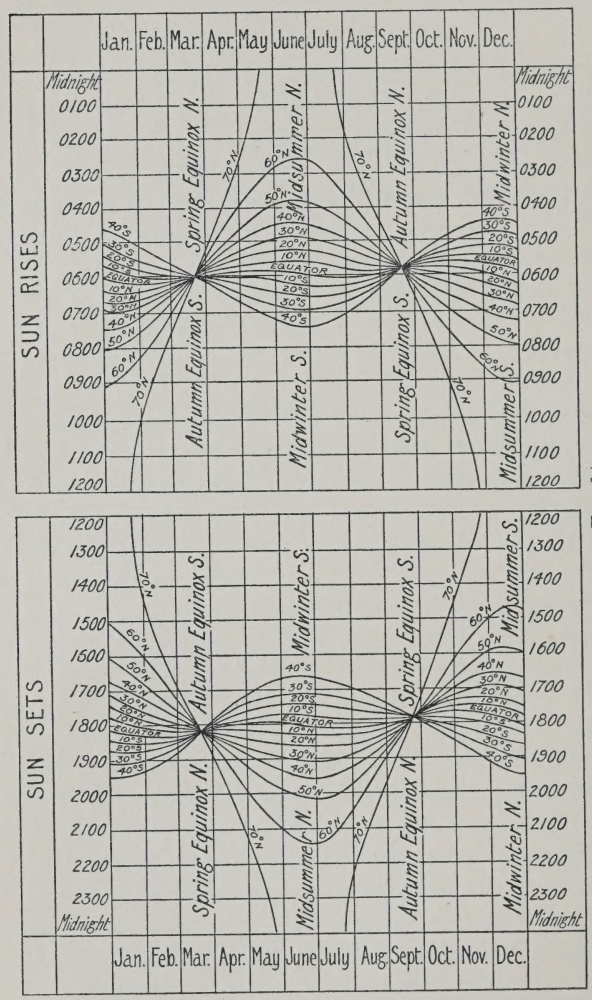


FIG. 14.

NOTES.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian $\frac{\text{add}}{\text{subtract}}$ 4 mins.

Summer Time. When Summer Time is in force add 1 hour.

These times do not hold good for other places in the United Kingdom; the times at Edinburgh, for instance, may vary

from them by as much as 40 minutes. A universal table is therefore necessary, and such a table is given in the "Field Service Pocket Book." A more convenient way, as it saves a slight amount of calculation for interpolations, is a diagram such as is given in fig. 14.

Example.—Required, the time of sunrise and sunset in lat. 43° N. on May 22. Draw a pencil line on the chart $\frac{3}{10}$ of the way between the lines for 40° and 50°. It cuts a line corresponding to May 22 at about 0433 for sunrise and 1921 for sunset.

In addition to the more obvious facts which this table brings out, namely that at midsummer the days are longest and at midwinter shortest, that at the equator all days are practically equal, and that at the equinoxes days and nights are equal all over the world, we may notice :—

(*a*) The irregularity of the line representing the times of sunrise and sunset at the equator; this is largely due to what is known as the equation of time, which is explained later. This affects all the curves equally, but is more noticeable near the equator, where the curves are flatter.

(*b*) The daily variation in the time of sunrise and sunset is greatest at the equinoxes and least at the solstices.

Tables of times of sunrise and sunset postulate a level plain. If a range of hills lies to the east or west of the observer, the sun will, of course, rise later and set earlier.

Sun overhead.

41. As we have already seen, the Sun is vertically overhead only at places in the Tropics, and at those places only twice a year at noon. The dates on which this will take place are the dates when the Sun's declination is equal to the latitude of the place (see para. 32).

Twilight.

42. The short duration of twilight is very noticeable in the Tropics. The reason of this is that as the Sun descends nearly vertically, it reaches a given distance below the horizon sooner than in temperate regions, where it sinks more obliquely. Twilight before sunrise is affected in a similar way.

In many almanacs the duration of twilight is given; this means the time that elapses from sunset till the Sun is 18°

below the horizon. In the United Kingdom we find in almanacs the expression " twilight all night " for a certain period in June and July.

Bearing of sunrise and sunset.

43. It is a vague generalization to say that the Sun rises in the E. and sets in the W. At the equator the Sun may rise (according to the time of year) anywhere between E.N.E. and E.S.E. and set anywhere between W.N.W. and W.S.W., while in the Arctic circle the sun may rise according to the time of year anywhere between N. and S. round by E. and set anywhere between N. and S. round by W. It is, however, true everywhere on the Earth's surface that at the equinoxes the Sun rises due E. and sets due W., and for a few weeks round these periods the direction varies little from due E. and W.

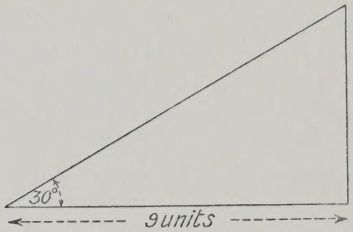


Fig. 15.

It is often useful to know what the bearing of the Sun at sunrise and sunset will be; the horizontal rays of the Sun make seeing very difficult, and the direction of sunrise and sunset must be avoided when, for instance, setting out an aiming point for gun-laying. The Sun's horizontal rays make seeing so difficult that a rush on a piquet, for instance, has a greater chance of success when directed along them than elsewhere, as the piquet would be almost blinded. The bearing of sunrise and sunset can be found from diagrams given in Appendix II, or approximately by a simple calculation.

It is necessary first of all to find the Sun's declination. This can be done from the table at the end of Chapter III (para. 32).

For instance, on April 21 the Sun will be about + 12°; on January 11 — 22° and so on.

Suppose, now, we want to find the bearing of sunrise and sunset on April 15, in lat. 30° N.

The Sun's declination on this date will be about + 9°. On any convenient scale draw a line AB equal to 9 units (fig. 15). Describe an angle CAB equal to the latitude of the place (30°). Draw CB perpendicular to AB. Then measure AC. We find it to be about 10·4 units. Sunrise and sunset will take place 10·4°, say 10½° N. of true E. and W. respectively. In

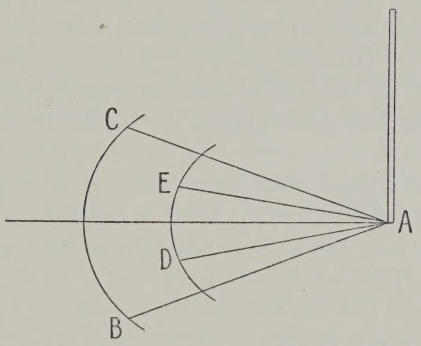


Fig. 16.

other words, the Sun's bearing will be 79½° at sunrise and 280½° at sunset.

True N. and S. of the Sun.

44. Apart from the differences due to the use of zone standard time and summer time to be described in Chapter VI, the Sun may be a considerable distance off the meridian at noon by the watch. But the Sun is always at its highest point when it crosses the meridian, and hence if we can determine its highest point we find a true N. and S. line with some approach to accuracy. A method of getting this direction is given below.

Fix a straight post firmly into the ground and make sure that the post is upright. Observe the shadow AB of the post an hour or two before noon. With centre A and radius AB describe a circle. Now observe when the end of the shadow

of the post again touches the circle (say at C). Join AC and bisect the angle BAC; the bisector will be a true N. and S. line.

If greater accuracy is desired another angle DAE can be described; if the bisectors of the two angles do not coincide, the mean position should be taken. Better results can be got by suspending a plumb-bob from an oblique pole, and observing the shadow of the plumb-bob. But at the best the method is not nearly as accurate as that of finding true N. and S. by the stars (see Chapter IX), and can hardly be relied on at all in the Tropics. The "Manual of Map Reading" gives a similar method with a pencil stuck to a plane-table by sealing-wax.

True N. and S. by watch.

45. A method of finding true N. and S. is given in the "Manual of Map Reading and Field Sketching," 1921, as follows :—

"By watch—lay the watch flat, with the hour-hand pointing to the Sun. The direction of true south is then midway between the hour-hand and twelve in the Northern hemisphere. In the Southern hemisphere point twelve to the Sun; then true north lies midway between twelve and the hour-hand.

"Thus in the Northern hemisphere, time 1500. With watch set as described above, south lies in the direction of 1330 (1.30 p.m.) and north in the opposite direction. This method is very rough. It is of no use in the Tropics. The farther away from the equator the more accurate it becomes."

The last paragraph is specially important. In Great Britain the method is fairly accurate; in India it is useless in the summer, and at other times almost useless except perhaps in the north in winter. In the Tropics, where the Sun travels from nearly E. due overhead and then travels W. again, any useful result is obviously quite impossible.

Diagrams in Appendix II.

46. The above-described methods of finding direction by the Sun are only approximately correct. If the Sun's bearing at any time is known, it is an easy matter to find true north. For this purpose the diagrams given in Appendix II have

been inserted. These show the Sun's bearing for every tenth degree of latitude. For intermediate latitudes a slight calculation is necessary.

Example.—Required, the Sun's bearing in lat. 34° N. at 1020 on April 17.

In lat. 30°, bearing would be	126°
In lat. 40°, „ „	110°
Difference	16°.

Difference for 4° = $\frac{4}{10}$ of 16 or 6·4°.
Therefore the bearing in lat. 34° would be 119·6°—say 120°.

It is to be noted that the diagrams have to be corrected for standard time and summer time (described in the next chapter) as noted at the foot of each chart; and that the horizontal scales for the diagrams for lats. 70°, 60° and 50° N. are different from those for the rest, as 24 hours have to be allowed for.

Maps are seldom so bad, or landmarks so deficient, that marching on a bearing has to be resorted to in daylight. Should such marching, however, be necessary the diagrams in Appendix II will be found useful.

Example.—Required, on Feb. 12, in lat. 28° N., to march on a bearing of 240°.

At 0800 the Sun's bearing (calculated as in the example above) is 114°. With the aid of a protractor, or with a specially constructed angle, select a point on the horizon such that the angle Sun-Observer-Point is 126°, and march on the point. The point will, of course, be to the observer's right-rear as he is facing the Sun. The corresponding point to the left-rear would be on a bearing of 348°.

For this purpose the observation should be taken when the Sun is low. At an altitude exceeding 45° it is difficult to get an exact aim.

Sun-compass.

47. A party of officers who escaped from Yozgad in Asia Minor in 1918 [1] provided themselves with a sun-compass consisting of a circular card graduated in degrees (fig. 17) with a stiff wire fixed, exactly perpendicular, in the centre. To use the compass it is necessary to know the Sun's bearing at the

[1] See " 450 Miles to Freedom," by Capt. K. L. Yearsley, M.C., R.E.

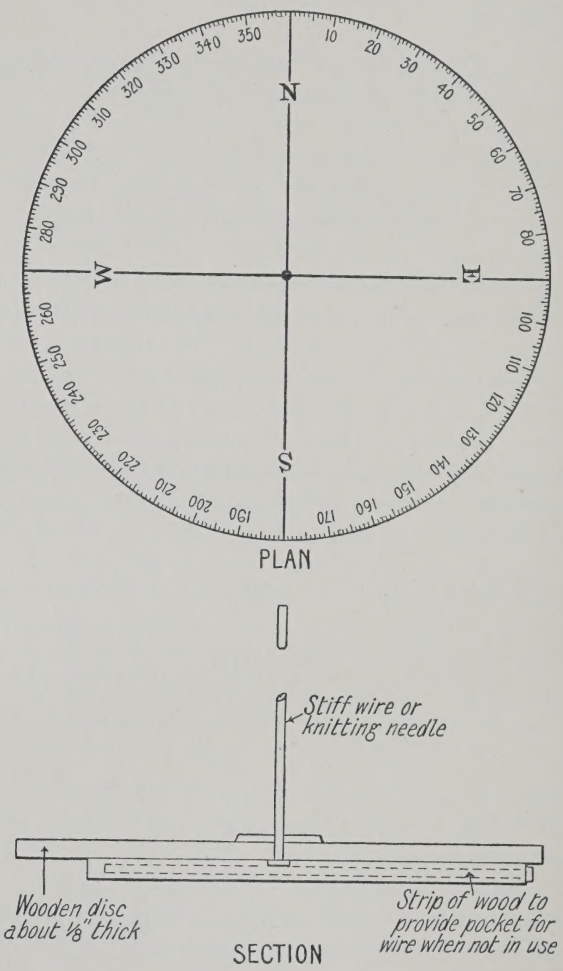


FIG. 17. Sun Compass.

time and the latitude. The former can be found from the charts at the end of this book (Appendix II).

Example.—Required, to march on a bearing of 125° at 1000 on Sept. 20 in lat. 30° N.

From the chart in Appendix II the Sun's bearing is taken as 116°. The shadow of a vertical object will therefore bear 296°. If, therefore, the compass be held perfectly horizontal, and the shadow of the wire made to coincide with the gradation 296° on the card, the compass will be set. March in the direction indicated by 125°.

It is evident that the greater the elevation of the Sun the less the accuracy of the method.

Time by Sun.

48. These diagrams could also be used as a rough method of finding the time, if true north is known.

Example.—In lat. 34° S. on July 17, the Sun's bearing is found to be 55°.

From the diagram for 30° S. the Sun's bearing is 55° at about 0820.
„ „ „ 40° S. „ „ „ 0812.
Difference for 10° is therefore 8 minutes.
„ 4° „ 3 minutes.
The time is therefore about 0817.

This method is, however, only approximate.

Sun's altitude.

49. It is sometimes of importance to know what the Sun's altitude is at a particular time. For example, given the Sun's altitude, the height of an object can be calculated from the length of its shadow. In the design of certain military buildings, such as hospital wards, operating-rooms, workshops, etc., it is also useful to know at what angles the sun's rays will strike a wall or a window. We have already seen how to calculate the Sun's altitude at noon. This information, as well as the Sun's altitude at any other time of day, is given in the diagrams in Appendix II. In the diagrams for tropical latitudes it will be noticed that the bearing lines converge at two points in each diagram. The Sun's altitude at each of these points is 90°. The altitudes for latitudes intermediate between those given in the diagrams can be found by interpolation, in the same way as bearings. Thus in 18° S. the Sun's altitude at 0700 on Mar. 9 is about 13°.

Example.—On an aeroplane photograph, taken in lat. 45° at 16.50 on April 27, the shadow of a tower vertically below the aeroplane measures 110 feet. Required, the height of the tower.

At the date given the Sun's altitude can be worked out from Appendix II as 22°. $\frac{\text{Height}}{110}$ therefore = tan 22°. From Appendix II we find that tan 22° = ·404. Hence the height of the tower is 110 × ·404 or 44 feet.

Example.—In lat. 34° N. a rectangular building, whose sides bear 105° and 195° respectively, has to be used as a hospital ward. It is desirable to protect by screens such of its walls as receive the Sun's rays at a steeper angle than 30°. Which of its sides need protection? A plan of the building is shown in fig. 18.

N. side. The sun will shine on this wall from its rising until it reaches a bearing of 105°. Between 75° and 105°, however, its rays will strike

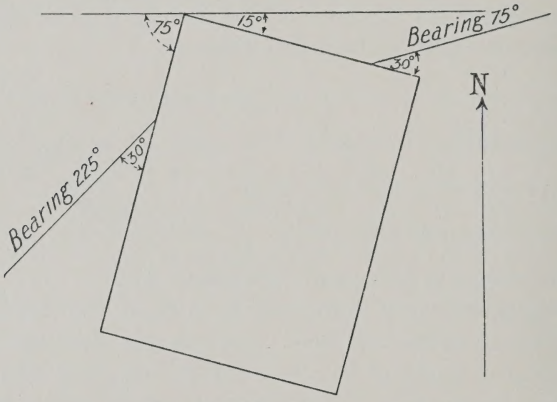


Fig. 18.

the wall at an angle of less than 30°. We need therefore only consider the Sun's altitude when its bearing is 75°, and we find from an examination of the diagrams in Appendix II that its maximum elevation would never exceed 20°. This side will therefore not need to be protected.

The E. and S. sides would obviously need screens.

W. side. The Sun's rays at a bearing of 225° have to be considered. The Sun's maximum elevation at this bearing is about 74°, consequently this side will need a screen.

We mentioned earlier in this chapter that the times of sunrise and sunset were affected when the Sun rose or set behind a range of hills. Appendix II enables the calculation to be made very simply provided the elevation of the top of the range is known.

Example.—In lat. 36° N. a range of hills lies due E. of the observer. The elevation of the top is 8°. Required, the time of sunrise on May 5.

In lat. 40° N. the Sun reaches an elevation of 8° at 0540.
„ 30° N. „ „ „ „ 0555.
Difference for 10° 15 minutes.
„ „ 4° 6 minutes.
Time of sunrise about 0546.

Hottest time of day.

50. It does not, of course, follow that the hottest time of the day occurs when the Sun is highest in the heavens. The temperature depends to such an extent on soil, climate and weather that no definite rule can be laid down, but in general it may be said that the early afternoon is the hottest time of day. The comfort of marches in hot climates depends to such an extent on temperature that it is quite worth while making a chart of thermometer readings throughout the day. Vagaries of the weather apart, a chart once made will do as a general guide for some weeks ahead. The coldest time of the twenty-four hours is usually at or a little before sunrise.

Latitude from elevation of Sun.

51. It is rare that on field service one would be so unprovided with maps as to make an approximate method of finding one's latitude of any practical use. But were that the case, it would be very easy to find the latitude from the Sun's elevation at noon. The simplest method of finding the elevation is by measuring the shadow of an object of known height.

Example.—On March 17 at noon in the N. hemisphere the shadow of a vertical object 10 ft. high measures 11 ft. 4 in. Required, the latitude.

The tangent of the Sun's altitude is $\frac{10}{11{\cdot}33}$, or ·88. From Appendix I we find the angle to be about 41½°.

The Sun's declination on March 17 (as found from the table in para. 32) is about 1½° S. The altitude of the celestial equator at the point where it crosses the meridian is therefore 41½° + 1½° = 43°. The altitude of the elevated pole will be 90 − 43° = 47°, which gives us the latitude.

In the S. hemisphere the calculation is similar.

Example.—On Oct. 7, at noon in the S. hemisphere, the shadow of a vertical object 12 ft. 6 in. high measures 9 ft. 8 in. Required, the latitude.

The tangent of the Sun's altitude is $\frac{12{\cdot}5}{9{\cdot}23} = 1{\cdot}29$. The Sun's altitude is therefore about 52¼°. The Sun's declination on Oct. 7 is about 5½° S.

The altitude of the intersection of the celestial equator and the meridian will be $52\frac{1}{4} - 5\frac{1}{2}° = 46\frac{3}{4}°$. The altitude of the elevated pole will be $90 - 46\frac{3}{4}° = 43\frac{1}{4}°$, which gives us the latitude.

Eclipses.

52. Eclipses of the Sun are rare phenomena and are hardly likely to affect military operations.[1] A list of forthcoming eclipses is given in *Whitaker's* and other almanacs. From Chapter VII it will be evident that eclipses of the Sun can only take place at New Moon.

Solar halos.

53. Halos round the Sun are luminous circles at a distance of about 22° from it, seen when there are light clouds between us and the Sun. They are commonly supposed to foretell a change of weather, but as they occur only when there is a particular thickness of cloud, they foretell a change of weather only to the same extent as is indicated by the existence of these clouds.

[1] It is said that an unexpected eclipse occurring during the Nile operations in 1884 caused the publication of the *Sudan Almanac*. An eclipse of the Sun occurring during a battle between the Medes and Lydians in 625 B.C. caused great consternation in both armies. The date of this eclipse gives a starting-point for chronology.

CHAPTER VI

THE MEASUREMENT OF TIME

Time.

54. It is advisable at this point to consider the way time is measured. Our time measures are derived from observations of the apparent movements of the Sun and stars. A year is the time taken by the Earth to revolve round the Sun, and is equal to 365 days 5 hours 46 minutes and a fraction; that is to say, after the lapse of this time the Earth will have returned to the same relative position, with regard to the Sun and stars, as at the beginning of the year.

Length of year.

55. If instead of solar days, which we may define as the interval of time between noon and noon at any point on the Earth's surface, we take rotations of the Earth on its axis, we find that there are 366 and a fraction in a year. The difference of one day between this and the number of solar days in the year is accounted for by the fact that the Earth has been travelling round the Sun, so that, regarding the Earth as fixed, the Sun has moved round the Earth once less than the stars have seemed to do. A sidereal day is therefore $\frac{1}{365{\cdot}24}$ of a day more than a solar day; this fraction works out at about 4 minutes. The effect of this on the apparent motions of the stars is explained in Chapter XI.

Leap years.

56. The fraction of a day over 365 days in the length of the year is allowed for by the extra day in leap years, which occur whenever the date is divisible by 4 (other than a century year), and in the century years only when the first two digits are divisible by 4. A calendar from 1924 to 1930 is given in Appendix III.

Length of month.

57. A calendar month differs from a lunar month, which

is about 29½ days. The time of full or new Moon therefore falls a day or two earlier every month (see para. 79).

Muhammadan calendar.

58. Twelve lunar months differ from twelve calendar months by about 10 days, and for this reason the Muhammadan year, which contains exactly 12 lunar months, begins 10 days earlier every Christian year. Year 1342 of the Hijrah began on Aug. 14, 1923; year 1343 begins on Aug. 4, 1924. The Muhammadan month begins at the sunset when the new Moon is first visible. This cannot be accurately foretold to a day, and hence the prediction of Muhammadan dates is uncertain to this amount. Those who have to deal with Muhammadan soldiers or labourers have to take Ramazan, the month of abstinence, into account. This shares with other Muhammadan dates the peculiarity of falling ten days earlier each year. In 1923 Ramazan began on April 17.

Difference between sun time and watch time.

59. However accurate one's watch may be, it does not give true solar time. There are three separate and distinct causes of variation. They are that due to what is known as the equation of time, that due to the use of standard time, and that due to " daylight saving " or " summer time."

Equation of time.

60. To begin with the equation of time; it was explained in Chapter IV that the Earth's velocity in its orbit varied, being faster when the Earth is nearer the Sun and slower when it is farther away. Its rotation on its axis is, however, at a constant rate. The effect of this is that the day, measured from noon to noon, or from midnight to midnight, varies, being shorter in January than in July. It would be extremely inconvenient to have to alter clocks and watches to meet this irregularity, and consequently the mean length of the day is taken as the standard. Noon, by which is meant the local time at which the Sun is on the meridian, is therefore not always at 12 o'clock, but may vary from it by as much as 16 minutes. *Whitaker's Almanack* gives the exact amount which has to be added to or subtracted from the apparent time to find true solar time. These amounts are shown as a graph in fig. 19. Thus on Feb. 1, we find in *Whitaker* for 1923

the remark, " Add to apparent time 13 m. 39 s." This means that the clock is in advance of the Sun by that amount, and that the Sun does not reach its highest point until 13 m. 39 s. after 1200 by the clock. The amounts are always allowed for in the tables of sunrise and sunset, and in all relevant diagrams in this book.

Thus the Sun and the clock agree only at certain instants on four days in the year, *i.e.* April 16, June 14, Sept. 2, and Dec. 25.[1]

This difference between the clock and the Sun is the chief reason for the irregularity in the curves in fig. 14, showing

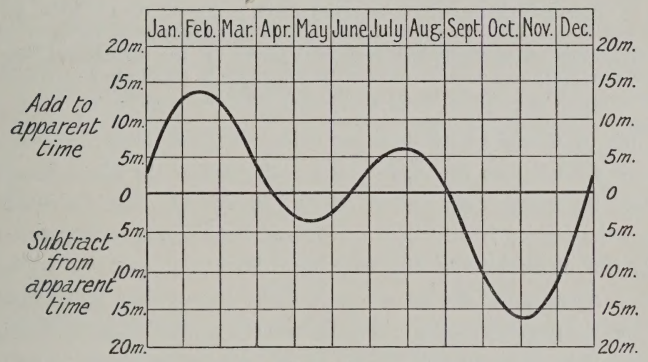


FIG. 19.

the times of the Sun's rising and setting at the equator, which otherwise would be almost straight lines. The same effect is noticeable in the diagrams in Appendix II.

Standard time.

61. The second cause of the disagreement between the Sun and the clock is due to the use of " Zone Standard Time." Standard time in Great Britain and Ireland is taken from the meridian of Greenwich. The time is known as Greenwich Mean Time (G.M.T.). Only at places on this meridian will noon take place at the same time by the clock as at Greenwich.

[1] The agreement of the Sun and clock sometimes takes place on the days preceding or following those given above, for reasons connected with the nearness or otherwise of the year to Leap Year.

As we go west, the time of noon will fall 4 minutes later for every degree of longitude. An example will make this clearer.

At Bristol (long. 2° W.), on March 1, at what time will noon take place?

From fig. 19, add to apparent time	12½ minutes.
For 2° W. add 2 × 4	8 minutes.
Total	20½ minutes.

Noon will therefore take place at 1220 G.M.T.

The same correction has to be made as regards the times of sunrise and sunset, but in this case latitude must also be taken into account.

Example.—At Belfast (lat. 54° 40′, long. 6° W.) what time will the Sun rise on March 1? From fig. 14, we find the time of sunrise to be about 0655. This table, as explained already, allows for the equation of time. We therefore have only to add for the difference in longitude 6 × 4 = 24 minutes. The Sun will therefore rise at 0719 G.M.T. on March 1.

Zone Standard Time.

62. It would be most inconvenient if Greenwich time were used all over the world, for then each part of the globe would have its own peculiar connections between the Sun's position and the clock. In China, for instance, 1200 would be registered on the clock late in the evening. So every country works by a meridian of its own, and in order to simplify matters as much as possible, most countries use a standard time differing from that of Greenwich by an exact number of hours or half-hours.

Thus, in India, the standard meridian is that of 82½° E. longitude. This represents a difference of 5½ hours. When, therefore, it is 1200 at Greenwich it is 1730 in India, and when it is 1200 in India it is 0630 in England. The effect of summer time on this adjustment is explained later.

The zones with which the military reader is most likely to be concerned are as follows :—

Fast or slow on Greenwich time.	Meridian.	Chief countries in the zone.
12 hours fast.	180° E.	Fiji Islands.
11½ ,, ,,	172½ ,,	New Zealand.
11 ,, ,,	165 ,,	New Caledonia and dependencies, Caroline Islands (E. of 154° E.), Marshall Islands.

Fast or slow on Greenwich time.	Meridian.	Chief countries in the zone.
10 hours fast.	150 E.	Victoria, New South Wales, Queensland, Tasmania, Papua, Caroline Islands (W. of 154° E.), Marianne Islands (except Guam).
9½ ,, ,,	142½ ,,	S. Australia, Northern Territory of Australia.
9 ,, ,,	135 ,,	Japan, Korea, Yap (Caroline Islands).
8 ,, ,,	120 ,,	W. Australia, E. China, Port Arthur, Hong Kong, Philippine Islands, Formosa and Pescadores Islands, North Borneo and Labuan, Macao, Portuguese Timor.
7 ,, ,,	105 ,,	French Indo-China, Siam, Federated Malay States, Straits Settlements.
6½ ,, ,,	97½ ,,	Burma.
5½ ,, ,,	82½ ,,	India (except Calcutta), Ceylon.
5 ,, ,,	75 ,,	Portuguese India, Chagos Archipelago.
4 ,, ,,	60 ,,	Mauritius, Seychelles, Reunion.
3 ,, ,,	45 ,,	'Iraq, Aden, French and Italian Somaliland, Madagascar.
2½ ,, ,,	37½ ,,	Kenya and Uganda.
2 ,, ,,	30 ,,	Turkey, Greece, Bulgaria, Rumania, Russia, Egypt, Rhodesia, Union of South Africa, Portuguese East Africa, Cyprus, Finland.
1 hour ,,	15 ,,	Sweden, Norway, Denmark, Germany, Luxembourg, Austria, Hungary, Switzerland, Italy, Yugoslavia, Malta, Czechoslovakia, Tunis, Nigeria, French Equatorial Africa, Cameroons, Belgian Congo, Portuguese West Africa, South-West Africa, Libya.
Greenwich time.		Great Britain and Ireland, France, Belgium, Spain, Portugal, Gibraltar, Algeria, Morocco, Ivory Coast, Dahomey, Senegal, Liberia.
1 hour slow.	15° W.	Iceland, French Guinea, Sierra Leone.
2 hours ,,	30 ,,	Azores, Cape Verde Islands.
3 ,, ,,	45 ,,	Eastern Brazil.
4 ,, ,,	60 ,,	Eastern Canada, New Brunswick (E.), Nova Scotia, Porto Rico, Trinidad, Leeward Islands, British West Indies (except Jamaica), French West Indies, Central Brazil, Argentina, Uruguay.
4½ ,, ,,	67½ ,,	Venezuela.
5 ,, ,,	75 ,,	Western Labrador, Quebec, Ontario to 82° 30′ W., New Brunswick (W.), United States (Eastern zone), Jamaica, Panama, Peru, Western Brazil.
6 ,, ,,	90 ,,	Central zones of Canada and the United States.
7 ,, ,,	105 ,,	Mountain zones of Canada and the United States.
8 ,, ,,	120 ,,	British Columbia and Pacific Coast zone of the United States.
9 ,, ,,	135 ,,	Yukon (Canada), Alaska.
11½ ,, ,,	172½ ,,	Samoa.

Practically this system affects one when crossing the frontier between two countries using different time, when watches have to be put on or put back. Thus, travelling from New York to San Francisco one has to put the hands of one's watch back by one hour three times when crossing the boundaries of the various zones (see table above). Returning from the Pacific to the Atlantic, one has to advance the hands.

It is to be remarked that the Germans and ourselves on the Western Front, and the Turks and ourselves in Mesopotamia, used different times.

The question is often raised as to what happens when one crosses the 180° meridian. The answer is that, if one crosses the meridian from east to west a day is omitted in the ship's log; while in the log of vessels travelling from west to east an extra day, called "Antipodes Day," is inserted.

Time at sea.

63. A scheme similar to that of Zone Standard Time has now been introduced for Royal Naval and other ships. The Ocean is divided into zones, each 15° of longitude in width. In the zero zone, which extends from $7\frac{1}{2}$° E. of Greenwich to $7\frac{1}{2}$° W. of Greenwich, the time used is G.M.T. Westward of this the zones are numbered + 1, + 2, etc., up to + 12, and eastward − 1, − 2, etc., up to − 12. The + 12 and − 12 zones differ from the rest in being $7\frac{1}{2}$° in width only, stretching as they do between $172\frac{1}{2}$° W. and 180°, and $172\frac{1}{2}$° E. and 180° respectively. The hands of the clock are set forward or back when the dividing line between two zones is crossed. The G.M.T. of an event occurring at noon by the clock in zone + 2 would be 1400, and so on. A modification occurs when a peninsula crosses the boundary between two zones, *e.g.* Spain and Portugal. The whole of the west coast of this peninsula lies in the zero zone, although it extends considerably west of $7\frac{1}{2}$° W. This modification is made to avoid the necessity of altering clocks forward and back again for ships rounding the peninsula.

Combination of two preceding variations.

64. We will now consider an example involving the two discrepancies (equation of time and Zone Standard Time) already explained.

Example.—At Rawalpindi (long. 74° E.) what is the local time of noon on Nov. 10?

From fig. 19 we find that 16 minutes have to be subtracted from apparent time. As Rawalpindi takes its time from the meridian of $82\frac{1}{2}°$ E., we have to add $(82\frac{1}{2} - 74) \times 4$ or 38 minutes to apparent time. The net difference is therefore 38 — 16, or 22 minutes to be added to apparent time. Noon therefore takes place at 1222.

The above paras. show the necessity, pointed out in Chapter I, for every officer to know the longitude of his station.

Local time still in use.

65. In a few countries where standard time is fixed, local time is still found in some places. In Calcutta, for instance, local time, 24 minutes in advance of standard time, is used. In Bombay standard time is used in military and Government offices, railway stations, and by British residents generally; but local time, which is 39 minutes slow, prevails in the city and municipal offices.

Summer time.

66. The third cause of variation between Sun and clock is that introduced by daylight saving or summer time, the object of which is to save artificial light by making use of the long summer evenings. In Great Britain and Northern Ireland, at 0200 on the morning of the day next following the third Saturday in April,[1] clocks are put on one hour; at 0200 on the morning of the day next following the third Saturday in September, clocks are put back one hour. Thus during the whole of the intervening period the clock is one hour in advance of the Sun, and one hour must be added to G.M.T. of all astronomical phenomena.

Example.—On May 15 what will be the time of sunset at Edinburgh (lat. 56° N., long. 3° W.)?

From fig. 14 we find the time about 2000.

Add for difference of longitude $3 \times 4 = 12$ minutes.

Add for summer time . . . . . 1 hour.

Answer 2112

[1] Or if that day is Easter Day, the day next following the second Saturday.

Summer time is in use in many countries besides Great Britain. It is not employed in the Tropics, for, as the day there approximates to 12 hours in length, little purpose would be served by advancing clocks. Summer time when in use therefore affects the time of all astronomical phenomena. In fig. 14 we must advance the times of sunrise and sunset by one hour. In the diagrams in Appendix II, we must similarly add one hour to all times given. Zone Standard Time is affected, and the Greenwich time zone for countries using summer time becomes one hour fast, the one-hour-fast zone becomes two hours fast, and so on. We saw that when it was 1200 in England it was 1730 in India. This statement must be modified when summer time is in force in England, for India does not use summer time. 1200 (summer time) in England is equivalent to 1630 in India.

Twenty-four-hours clock.

67. The "twenty-four-hours clock," used throughout in this book, was adopted in the British Army towards the end of the Great War for all purposes, and is still employed in training manuals and during active and training operations. It was in use in India and on the Continent for railway time tables and many other purposes long before this. One peculiarity of the Army system is that there is no equivalent for midnight—an event happening at that time is said to take place at 2359 or 0001. For the benefit of the uninitiated a few typical equivalents are given :—

Old system.	24-hours clock.
12.1 a.m.	0001.
1.0 a.m.	0100.
10.0 a.m.	1000.
1.0 p.m.	1300.
11.51 p.m.	2351.

In the *Nautical Almanac* and other astronomical publications a twenty-four-hours clock is in use, beginning at 1200 G.M.T. Thus 1.17 corresponds to 13.17, and 13.17 to 01.17. With effect from Jan. 1, 1925, however, this system is to be abandoned

and the twenty-four-hours clock, beginning at midnight, will be introduced.

Astronomical clocks and watches are divided into 24 instead of 12 hours, and mean time watches of this kind can be obtained.

Different style of reckoning.

68. In some countries clocks and watches are in general use, but a system of reckoning time different from ours prevails. In 'Iraq, the inhabitants reckon from sunrise, which is 12 o'clock, and noon therefore varies between about 5 and 7 o'clock according to the time of year. Watches have therefore to be regulated every few days, and it is impossible to tell, without a calculation, what time corresponds to standard time. The day is usually reckoned by Muhammadans from sunset to sunset.

Regulation of clocks.

69. To regulate a watch or clock accurately, *i.e.* to discover by what amount it gains or loses daily, it is necessary to observe the time at which a fixed star passes a given point on two, or preferably more, successive nights. A star near the celestial equator is the best to take, and should be at some distance, say 40°, above the horizon. It should be observed when setting behind a high hill or the roof of a house to the west, so as to obtain the necessary elevation. For backsight, a pin stuck into a windowsill will do, and the moment of the star's disappearance must be observed and noted. Any fixed star (but not a planet) [1] crosses the same point at intervals of 23 hours 56 minutes 4 seconds, or 3 minutes 56 seconds earlier every night. The above method, it will be noted, is for regulating a watch and not for finding the time. Approximate methods of finding the time by the stars are given in Chapter XI.

Seconds.

70. A pendulum to beat seconds can be made by attaching a weight to a line 39·06 inches long. Any weight will do, provided it is heavy enough to keep the line taut. The length of the swing is immaterial. The line must be made of wire or some material which will not stretch.

Sundials.

71. The most usual type of sundial consists of a level plate,

[1] How to distinguish a planet from a star is set forth in Chapter XII.

on which hours and their subdivisions are graduated, and a triangle of metal, set accurately in a north and south line, perpendicular to this. The hypotenuse is inclined to the horizontal at an angle equal to the latitude of the place. It follows that sundials are useless if taken from the latitude for which they were constructed. Readings by sundial must be corrected for the equation of time, for Zone Standard Time and for " summer time."

In setting up a sundial, care must be taken that the triangle is exactly in a north and south line, and that the base plate is level.

There are other forms of sundial, notably the vertical type, but the horizontal type, described above, is the commonest.

Baseless belief.

72. There is an old superstition to the effect that when the Sun shines on a fire in a room the fire goes out. There is no truth in this belief. No doubt fires do go out when sunlight falls on them; but this is because the occupants of the room feel the need of the fire less in sunshine than in other times, and so fail to stir the fire or to provide fresh fuel. The matter has been made the subject of experiment, and the presence or absence of sunlight has been found to have no effect whatever.

CHAPTER VII

THE MOON

73. The Moon is a satellite of the Earth, round which it moves in a period having a mean value of 27 days 7 hours 43 minutes 11·5 seconds. But as during this time the Earth has performed nearly a twelfth of its journey round the Sun the interval from one New Moon to another is consequently greater, and amounts on the average to 29 days 12 hours 44 minutes 3 seconds. This period is called a "lunation." The orbit is elliptical, the Moon at perigee (or nearest to the earth) being 225,000 miles [1] and at apogee (farthest from the Earth) 252,000 miles [1] distant from the earth. When Full Moon occurs at perigee the Moon gives about a quarter more light than at apogee. Perigee does not occur at the same time each lunation, but works backwards. Thus perigee coincided within a few hours with Full Moon on Jan. 23, 1921. The next Full Moon to coincide with perigee was that of March 12, 1922. This orbit is inclined at about 5° to the ecliptic. The Moon's apparent path in the sky is therefore very close to that of the Sun, from which it never varies by more than 5° in declination. Moon.

In summer (northern hemisphere) the Full Moon will be found following much the same path as the Sun in winter, while at midwinter the Full Moon's greatest altitude approximates, within 5°, to that of the Sun at noon in midsummer. The two points at which the Moon's orbit intersects the ecliptic are called nodes. These nodes are retrogressing along the Moon's orbit, of which they make a complete circuit in 18 years.

The Moon's diameter is 2160 miles—rather more than a

[1] Mean distances.

quarter that of the earth. Its apparent diameter has a mean value of 31′.

Phases of the Moon.

74. The Moon, like the planets, shines by the Sun's reflected light. Consequently one-half of it is always bright and the other half dark. The reason of the phases of the Moon is that we see varying amounts of the lighted and dark hemispheres according to the relative positions of the Earth, Sun and Moon. The phases of the Moon can be exactly imitated by moving a tennis ball round one's head in daylight or lamplight, doing in a few seconds what the Moon takes a month to do, yet it is astonishing to find how many educated people believe that the phenomenon has something to do with the shadow of the Earth.

Moonrise and moonset.

75. The times of moonrise and moonset may profoundly affect military operations at night, yet it is astonishing what ignorance prevailed among educated people about this comparatively simple subject until the Great War and the frequency of the air raids caused it to be studied, and it is to be feared that much of this knowledge has by now been forgotten. Most calendars give tables, yet tables may not always be handy, and in any case it is useful to have a working knowledge of this subject in one's head.

At Full Moon, the Moon rises at sunset and sets at sunrise; this is true for every time of year and for every place on the Earth. After Full Moon it begins to *wane*, assuming what is known as a *gibbous* shape, and rises about 50 minutes later every night. At last quarter, or Half Moon, it rises at midnight, reaches its highest point (on the meridian) at sunrise, and sets at noon—though in this stage its setting is rarely observed. As the Moon continues to wane it rises later in the early morning, and is last seen as a thin *crescent* (*decrescent* is the correct term) in the E. sky just before sunrise. New Moon technically occurs when the Earth, Moon and Sun are in a straight line, but except in the case of a solar eclipse we do not see the Moon until at least a day after New Moon, when it is visible as a thin crescent in the W. after sunset.

It has, as a matter of fact, risen very soon after sunrise, but is quite invisible until the sky is moderately dark. A crescent Moon sets very soon after the Sun.

When the Moon is two or three days old the phenomenon of the "Old Moon in the New Moon's arms" can be seen. That is to say the dark part of the Moon can be seen shining with a faint ashy light. This is due to "earthlight"—the Sun's light reflected off the Earth. This phenomenon is generally believed to foretell rain; it is true that it has connection with the weather, which is better put as follows:—the earthlight can be seen only in very clear skies, such as often occur before, but more usually after, rain. When the Moon can be seen to set behind a high range of hills, so that there is no longer the effect of the contrast of the bright crescent, the earthlight is seen to be of considerable intensity.

As the Moon *waxes* it sets later, until at first quarter (or Half Moon) it sets at midnight, having risen at midday, when its rising is scarcely ever noticed. And so on to Full Moon, when, as previously stated, it rises at sunset and sets at sunrise.

These statements may be summarized as follows:—

A New Moon rises at sunrise and sets at sunset.

A Moon in its first quarter rises at noon and sets at midnight.

A Full Moon rises at sunset and sets at sunrise.

A Moon in its last quarter rises at midnight and sets at noon.

The age of the Moon is reckoned from New Moon. Thus a Moon in its first quarter is 8 days old, a Full Moon 15 days old, and a Moon in its last quarter 22 days old. The above information is shown in diagrammatic form in fig. 20.

If the age of the Moon is known, therefore, its time of rising and setting can be found approximately. Since in a lunar month the time of rising works round the 24 hours, it follows that the Moon rises $\frac{24}{29\frac{1}{2}}$ of an hour, or 48 minutes, later every night. This is the average value; the interval varies a great

Fig. 20. The Moon.

deal throughout a month—at Greenwich between 20 minutes and 1 hour 10 minutes. A rough rule giving the time of the Moon's crossing the meridian is as follows: Add ·8 of the Moon's age (in days) to 12, and the result, subtracting 24 if necessary, gives the time of the Moon's crossing the meridian.

Example.—Given the Moon's age as 17 days she will cross the meridian at $12 + (\cdot 8 \times 17) = 25 \cdot 6 = 0136$.

Harvest Moon.

76. The period of the month when the intervals are closest together differs at different times during the year. In September it falls at Full Moon, when the phenomenon is called "Harvest Moon." It is not, as many people imagine, that the Moon is necessarily bigger or brighter during the month, but that for several days in succession moonrise follows sunset at very short intervals, and in consequence the work of getting in the harvest can be continued after nightfall with little or no interruption owing to darkness. The following table shows the G.M. times of sunset and moonrise for Greenwich near Full Moon in August and September 1917.

Date.	Sun sets.	Moon rises.
Aug. 28	1855	1634
29	1853	1709
30	1850	1739
31	1848	1801
Sept. 1	1846	1822
2	1844	1841
3	1842	1902
4	1838	1924
5	1837	1953

Hunter's Moon.

77. In October this phenomenon is called "Hunter's Moon." The risings are closest in that month a little before Full Moon.

Conventional signs.

78. In northern latitudes the crescent is seen facing to the right, as the conventional sign in almanacs for the Moon in its first quarter shows it. The decrescent faces left (the conventional sign for a Moon in its last quarter is a black decrescent in this position). In the south temperate region these are reversed, and the young Moon is then seen facing left, while a waning Moon faces right. In the Tropics a

young Moon is seen "on its back" as is also a very old Moon, both being vertically or nearly vertically over sunset or sunrise.

Moon's age.

79. The following is a useful method of determining the Moon's age. From the year subtract 1911; multiply the remainder by 11; and from the product deduct as many multiples of 30 as are required to bring the result below 30. Call this X. Call the day of the month Y. Take a number for the month, Z, as follows :—

Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
0	2	0	2	2	4	4	6	7	8	9	10

Add X, Y and Z together, and if the result is over 30, deduct 30. The result is the age of the Moon, correct within a day.

Example.—Required the age of the Moon on Dec. 31, 1922.

$1922 - 1911 = 11.$

$11 \times 11 = 121.$

$121 - (4 \times 30) = 1 = X.$

$Y = 31.$

$Z = 10.$

$X + Y + Z = 42,\ 42 - 30 = 12.$

The Moon was new on Dec. 18 at 1220, and consequently the Moon was 13 days old at 1220 on Dec. 31.

Corrections to tables of moonrise and moonset.

80. Tables giving the times of moonrise and moonset need to be corrected (*a*) for latitude, (*b*) for difference in longitude from the standard meridian, (*c*) for summer time.

As regards (*a*) the difference is slight, especially in the Tropics, for variations in latitude less than 5°. Tables will usually be available giving the times of moonrise and moonset for places within twice this amount. For (*b*) and (*c*) the corrections are exactly similar to those for tables of sunrise and sunset, as explained in Chapter VI.

Lunar eclipses.

81. Eclipses of the Moon occur when the Moon is immersed in the Earth's shadow. They therefore can only occur at Full Moon; not every Full Moon, but only when Full Moon occurs near enough to one of the nodes in the orbit. A total eclipse may last for as much as two hours. Sometimes during totality the Moon is almost completely invisible; at other

times it shines with a dull yellow or copper hue as if shining through a cloud. The variation in brightness is due to the fact that the Moon is then lit up by the Sun's rays which have passed through and been bent by the Earth's atmosphere, which, as we know, varies greatly in transparency.

During the siege of Kimberley in 1899 searchlight messages from the beleaguered garrison were interfered with by a Full Moon, but, on a lunar eclipse occurring, the operators eagerly availed themselves of the opportunity of getting their messages through. A case is known to the writer when, on manœuvres, a retiring force took advantage of an eclipse of the Moon (the Moon rose eclipsed) to start a night march. The departure from bivouac did not, owing to the darkness, become known to the pursuing force until some time afterwards.

Lists of forthcoming eclipses are given in *Whitaker's* and other almanacs.

Lunar halos.

82. A halo round the Moon is produced by the same causes as a halo round the Sun; like a solar halo it does not necessarily foretell a change of weather.

The Moon and changes of weather.

83. Here it may be mentioned that there is no ground at all for the popular belief that changes of the weather are associated with changes of the Moon. It is difficult to say, from mere observation, whether the Moon is full on the 14th or 15th day of its age. A change of weather occurring on either of these days and probably one occurring on the 13th or 16th day, would be put down by those who, consciously or unconsciously, seek to maintain the theory, to the change of Moon. The same thing may be said of the other changes of the Moon. By the theory of probability more than half the changes of weather must occur during these periods, and changes occurring at other times are quite probably neglected or forgotten by one holding the aforesaid belief. Besides, changes of the Moon are simultaneous, or practically so, over the whole of the Earth; which is by no means the case with changes of the weather. Nor is there any foundation for the popular belief that sleeping in full moonlight has a deleterious effect on the sleeper.

Almanacs such as *Whitaker's* give the times of changes of the Moon for Greenwich. If these tables only are available in a country not using Greenwich time, the necessary correction for longitude must be made. Thus, if the time of Full Moon at Greenwich is 1500 on a certain day, it is approximately correct to say that in India it will be full at 2030 on the same day (the difference in time, as explained in the last chapter, being $5\frac{1}{2}$ hours). But it may be added that the difference in appearance between a Full Moon and one $5\frac{1}{2}$ hours from full is not noticeable to the naked eye.

Easter.

84. Easter Sunday, it may be said for all practical purposes, occurs on the first Sunday after the first Full Moon after the vernal equinox; it must therefore always occur between March 21 and April 25.

CHAPTER VIII

THE TIDES

85. TIDES may profoundly affect military operations on the sea coast or on tidal rivers. A working knowledge of the tides is therefore essential to anyone engaged in such operations. Tides and military operations.

For ports in civilized countries tide-tables are available, giving the times of high and low water and the depth of the water above a certain fixed level at these times. But for places on the sea-coast of uncivilized countries, where a British force may have to land, such figures are probably entirely wanting, and all that can be known beforehand is the times of the month and year when the highest and lowest tides are likely to happen.

86. The effect of the tides is twofold. The first is that a greater or less amount of foreshore is alternately covered and uncovered by the sea. The second is that the tide causes currents and retards or may reverse for a time the direction of flow in a river or estuary. The latter effect chiefly concerns naval operations, but cannot be entirely left out of account by embarkation and military landing officers, etc.; the former affects landing operations, depths of fords, landing of stores, etc., and so must be taken into account in military operations on a coast liable to tides of any magnitude. Effects of tides.

It is the connection of the Sun and Moon with the tides which makes the latter a subject which cannot be left out of a treatise on the military uses of Astronomy.

87. We may explain the tides briefly as follows :— Cause of tides.

The Moon attracts the water on the Earth's surface under it

more than it attracts the Earth, and consequently the water on this side is raised towards the Moon. The Moon also attracts the Earth more than it attracts the water on the far side of the Earth, which consequently is raised in a heap nearly as high as that on the near side of the earth [1] (see fig. 21).

It is, of course, equally true to say that the Earth attracts the Moon. The two are prevented from moving to meet each other by the fact that they are both in motion round the common centre of gravity, which falls inside the Earth about 3,000 miles from the centre.

Intervals between tides.

88. If now we remember that the Earth rotates round its axis once a day, and that the two heaps of water remain practically stationary under the Moon and on the side away from the

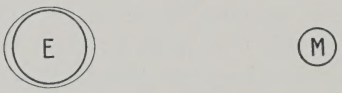


Fig. 21.

Moon, we see that a point on the Earth's surface will pass through a period of high water, then low water, then high water, then low water within 24 hours. Remembering also that in this 24 hours the Moon has travelled about $\frac{1}{29\frac{1}{2}}$ of its journey round the Earth, we see that the complete cycle will occupy 24 hours 48 minutes, and so obtain the first of our generalizations :—

A. At any seaport periods of high water succeed each other at intervals of 12 hours 24 minutes; low water occurs 6 hours 12 minutes after high water.

Tides near poles.

89. The intensity of the Moon's attraction at the Earth's

[1] This is the usual text-book theory and may be used as a working hypothesis. It may be mentioned, however, that though the Moon's attraction is the cause of the heaping up of the water, the direct pull of the Moon is the cause of an infinitesimal portion only of the "heap"; and that the "heap" is not directly under the Moon; and, finally, that the theory is complicated to an enormous extent by the irregular shape and depth of the earth's oceans.

poles is approximately equal to the intensity of its attraction on the Earth as a whole, and hence :—

B. The tides diminish in intensity from the equator to the poles.

Tides at perigee.

90. The nearer the Moon is to the Earth, the greater is its attractive force, so :—

C. The high tides are higher and the low tides are lower at perigee than at other times.

Spring tides.

91. The effect of the Sun on the tides is about two-ninths that of the Moon. At New Moon the Sun's pull reinforces that of the Moon, and *spring* tides are the result. At Full Moon, the Sun's pull serves to increase the height of the tide on the side opposite the Moon, and *spring* tides again occur. But at first and last quarter their pulls are in opposition to each other, and *neap* tides then happen. The greatest effect is not felt for two or three days after New and Full Moon respectively. Thus we have :—

D. Spring tides occur two or three days after New and Full Moon (those at New Moon being usually higher than those at Full Moon) and neap tides two or three days after the quarters.

The expression *spring* used above has no connection with the season of the year.

Equinoctial tides.

92. At the equinoxes, the Sun and Moon are in one plane, and hence especially high tides may be looked for then. Hence :—

E. The highest spring tides occur about the spring and autumn equinoxes (March 22 and September 22).

Times of high water.

93. The rate at which the tidal wave travels round the Earth, though not uniform, is regular to the extent that high water always occurs at a place at a definite interval of time after that at any other place. The standard time is taken as that of H.W. at London Bridge. The " establishment of a port " is the hour at that port of high tide following New or Full Moon. So :—

F. High water always occurs at a port the same interval of time earlier or later than at London Bridge.

Differences in level between successive tides.

94. As the Moon does not revolve round the Earth in the plane of the Earth's equator and the greatest elevations of tide are approximately under the Moon, it follows that a very high tide may be followed by a comparatively low high tide, which again is followed by another very high tide.

In fig. 22, for instance, there is a very high tide at 0. But as 0 travels round the earth it encounters first a low tide and then at 0′ a high tide very much lower than that experienced at 0. Proceeding onward, after another low tide, a high tide approxi-

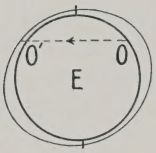


Fig. 22.

mately equal to that experienced the previous day will be met with at 0. Hence :—

G. As a result of periodical displacement of the Moon and Sun above and below the plane of the Earth's equator, the difference in successive tides may be very marked.

When the Indian Expeditionary Force was landing below Basra on the Shatt-al-'Arab in November 1914, the day high tides were very low, leaving a broad stretch of muddy foreshore over which horses and stores had to be landed; but the night tides were much higher and enabled loaded barges to be brought up over ground which was far above the high-water mark of the day tides.

General.

95. Tide-tables for London Bridge are given in most almanacs.

As stated above, the mean force of the Moon to produce tides is $4\frac{1}{2}$ times that of the Sun. Hence spring tides will be about $1\frac{1}{4}$ times the height of neap tides.[1]

[1] Spring tides are to neap tides as $4{\cdot}5 + 1 : 4{\cdot}5 - 1$ or 11 to 7.

96. Except as stated in B above, no rules can be given as to the height of tide to be expected at any place. This is entirely dependent on its geographical situation. In mid-Pacific the rise and fall is about 2 or 3 feet. At ports in smaller oceans like the Atlantic, it is as a rule larger. The greatest elevations occur in funnel-shaped openings like the Bristol Channel, where the tide occasionally rises to 50 feet; and in the Bay of Fundy, where the elevation is as much as 70 feet. In seas like the Mediterranean the rise and fall is very small, and in enclosed seas like the Black and Caspian there are no appreciable tides. Tides affected by situation.

Variations of a peculiar nature occur at certain places situated on the English Channel, where there are two high tides within half an hour, with a slight fall in between.

97. If there are no tide-tables for a seaside place, it is necessary to construct one. A gauge will have to be set up, and readings taken every hour or so. Two or three years' readings will be necessary before accurate tide-tables can be constructed, but one month's readings are good enough for approximate levels to be foretold, and even a day or two with the application of the rules given above will enable a forecast to be made, good enough for ordinary purposes. If the times of high and low water have been kept for a lunation, the same times will hold good for all subsequent months. Construction of tide-tables.

The accompanying chart (fig. 23), giving the height of tides at Bombay in May 1917, illustrates most of the above points.

If now we follow the chart, we find that at the beginning of the month tides are very low, the Moon having just passed its first quarter. The afternoon tides are rather higher than the morning tides. From then on the tides increase in height till the 10th, when a maximum is reached, 3 days after Full Moon. Thereafter the tides begin to decrease, and a minimum is reached about the 14th, the day of the last quarter. The height is greater than at the minimum at the beginning of the month, chiefly owing to the fact that the Moon is in perigee on the 13th. From the 14th the tides increase, and at the same time the

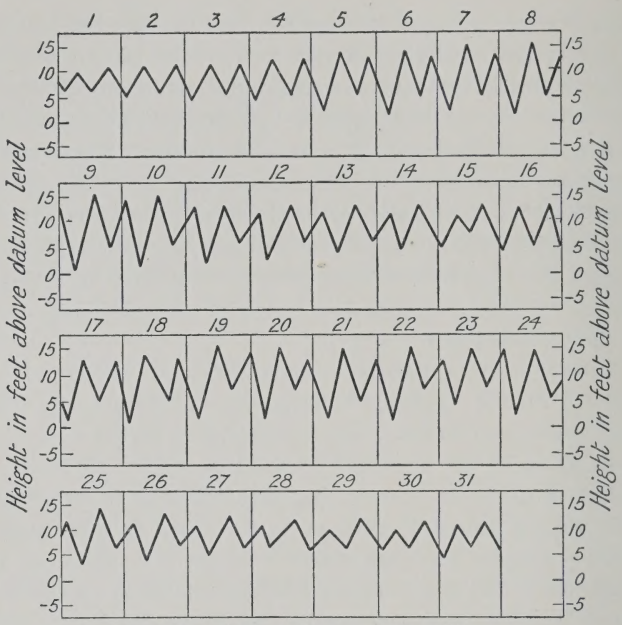


FIG. 23. Tides at Bombay, May 1917.

Explanatory Notes.

Full Moon			7th	0735
Moon in Perigee . . .			13th	2300
Last Quarter . . .			14th	1839
New Moon			21st	0538
Moon in Apogee . . .			28th	0200
First Quarter . . .			29th	0425
Highest high tide	15′	0″	21st	1158
Lowest high tide	9′	4″	1st	0727
Highest low tide	6′	10″	31st	1308
Lowest low tide	0′	11″	9th	0614
Greatest daily range	13′	11″	21st	
Least daily range	3′	0″	1st	

Establishment of the port 11h. 35m.

morning tides become equal to and then exceed those of the afternoon. On the 21st, the day of the New Moon, another maximum, the highest of the month, is encountered, after which the height of high tide again decreases until the minimum is reached again on the 29th.

98. Suppose now that we are in possession of the information given on the above chart—which as a matter of fact could have been plotted from readings of a simple tide gauge such as that we have described above—and wish to predict the tides for the next month, we should set about it as follows :— Time prediction.

The phases of the Moon and the times of perigee and apogee could be found from *Whitaker's Almanack ;* were this not available, it would be a simple matter to calculate them from the notes given in the preceding chapter. They are as follows :—

June 1917.

Full Moon . . .	5th	1758
Moon in Perigee . .	6th	0200
Last Quarter . . .	12th	1130
New Moon . . .	19th	1754
Moon in Apogee . .	24th	2000
First Quarter . . .	27th	2100

The times of high and low water can be found by adding successive intervals of 12 h. 24 m. to those of high and low water in May. On May 31, high water occurred at 1851, and low water at 1308. On June 1, therefore, high water will take place about 0715 and 1939, and low water at about 0132 and 1356, and so on. The value for the " establishment of the port " gives us the time of high water after Full and New Moon, *i.e.* 2335 on the 5th, and 2335 on the 19th of the month. We may expect high tides, as in May, soon after New Moon, with another maximum after Full Moon. It will be noticed that perigee is almost coincident with Full Moon, and that consequently very high tides may be expected at that period; as a matter of fact they surpass the New Moon tides. We may expect the lowest high tides soon after the quarters. The above deductions would enable us to construct a rough tide-table, not, of course, with the accuracy of a tide-predicting machine, but sufficiently near the truth to be of good service to troops engaged in landing or bridging operations.

99. The tide usually ebbs more quickly than it flows, consequently low water seldom occurs exactly halfway between Time of low water.

two high waters. On the other hand, at the mouths of rivers the tide may ebb for, say, ten hours and flow for the remaining two, while there is nearly always a period of still water at high and again at low water.

Effect of winds.

100. It must not be forgotten that winds may affect tides to a very great extent. High water will be increased and its time accelerated by an inshore wind, while an offshore wind tends in the opposite direction. Floods in tidal rivers raise the level of both high and low tides.

Bores.

101. In funnel-shaped estuaries the tide may come in with such force and suddenness as to cause a *bore* or tidal wave some feet in height. This phenomenon occurs fortunately in very few rivers. The Hughli at Calcutta is one of those most subject to bores, and the Severn and Yangtze-kiang are others.

CHAPTER IX

THE STARS

Uses of the stars.

102. We have already, in Chapter I, discussed the stars in a general way; we now come to their use in two very important ways as regards military operations; namely, for finding a given direction and for telling the time.

For the former, a knowledge of the motions only of the stars is necessary. The reader is reminded of the umbrella-simile in Chapter I.

For the latter purpose, viz. telling the time, it is not necessary to know the names of more than a dozen stars and constellations. The knowledge of the names of more is, of course, at all times very desirable, as it enables a star to be described in a word instead of by a long periphrasis.

Apparent movements.

103. We talk of the stars as "fixed," and for military purposes we may treat them as absolutely devoid of motion relative to one another. We need only consider their apparent motion due to the rotation of the earth, which motion has already been mentioned in Chapter I. It was there seen that every star appears to revolve round the celestial pole in a day. This must now be qualified by the remark that the time taken by a star to revolve round the heavens is about 4 minutes less than 24 hours. For, as the Earth rotates on its axis in the same sense that it revolves round the Sun, it performs roughly $366\frac{1}{4}$ rotations with regard to a fixed star during the time it performs $365\frac{1}{4}$ with regard to the Sun. This is the same thing as saying that there are $366\frac{1}{4}$ sidereal days in a year, or that a sidereal day is about 23 hours 56 minutes 4 seconds long.

Star charts.

104. The principal stars of the N. and S. hemispheres are shown in Plates I and II. It should be remarked that it is impossible to depict any portion of the sky on a plane surface

without distortion. The greater the area of sky the chart represents, the more in proportion does the distortion become. This is for the same reason that maps of the Earth on any scale are distorted, by an amount which becomes more noticeable the greater the area of the Earth's surface depicted. In Mercator's projection, for instance, Greenland is shown as large as Africa, although in reality it is just about a third as long and a third as broad.

The only accurate representation of the stars would be on the inside of a hollow sphere when one's eye was at the centre of it. It will be seen that it would be quite impossible to flatten out the substance of the sphere without distortion or breaking.

In Plates I and II the amount of distortion is greatest at the edges, where constellations are shown about $1\frac{1}{2}$ times as broad (measured E. and W.) as they should be in proportion to their length (measured N. and S.).

Names.

105. The stars were, very early in history, divided into constellations, representing, more or less fancifully, some animal or mythical hero. The stars in each constellation are named by the letters of the Greek alphabet, the brightest generally being Alpha, the second brightest Beta, and so on. This nomenclature is followed by the Latin name of the constellation in the genitive case—thus, Alpha Leonis is the brightest star in the constellation Leo or the Lion. Some of the brighter stars have what may be called pet names, that of Alpha Leonis being Regulus.

Magnitudes.

106. The magnitude of a star is its brightness, which is quite independent of its actual size. Stars of the sixth magnitude are just on the limit of visibility to the naked eye; a bright star such as Altair is said to be of the first magnitude, while the brightest of all (Sirius) is, rather curiously, said to be of $-1{\cdot}6$ magnitudes.[1]

Pole Star.

107. There is no star exactly at the North Pole. There

[1] First-magnitude stars are 2·5 times as bright as those of second magnitude, which in turn are 2·5 times as bright as those of the third magnitude, and so on.

is, however, one sufficiently close for most practical purposes. This is the Pole Star (Alpha Ursae Minoris), which is distant from the pole 1° 7′.[1] The altitude of the Pole Star is therefore an approximation of the latitude of the place.

The Great Bear.

108. Distant about 30° from the North Pole is the Great Bear (Ursa Major), the seven brightest stars of which are known as The Plough. These seven stars form only the tail and hind-quarters of the Bear, whose head and claws are formed by smaller stars. When these are taken into account the likeness to a bear is quite noticeable.

How to find the North Pole.

109. In para. 6 we discussed a method of finding the Pole Star. To find the North Pole by means of the Pole Star take a line from the Pole Star to a point in the tail of the Great Bear midway between the middle and last stars (Zeta and Eta Ursae Majoris). It is accurate enough for most purposes to say that the pole is on this line 1° from the Pole Star in the direction of Zeta and Eta Ursae Majoris. When Zeta Ursae is above or below the Pole Star, the latter will be approximately true north. When Zeta Ursae is due E. or W. of the Pole Star the North Pole is 1° 7′ E. or W. of the latter.[2]

Cassiopeia.

110. It may often happen, in N. latitudes below 30° N., that the Great Bear is invisible, in which case another constellation, Cassiopeia, may be used to find the North Pole. This constellation is situated on the other side of the pole from the Great Bear, being about as far distant from it. The five principal stars are shaped like a W. The Pole Star is 30° from the centre star of the W. (Gamma Cassiopeiae), the line joining this star to the pole being nearly at right angles to the line joining the former to the next following star, Delta Cassiopeiae.[3]

[1] This amount is slowly decreasing. It will reach a minimum of about 30′ about A.D. 2095, after which it will increase.

[2] The reader's attention is called to the note to art. 278 of the "Manual of Map Reading."

[3] A star is said to "precede" or "follow" another when it precedes or follows it across the meridian. Thus Delta Cassiopeiae is to the left of Gamma when the Constellation is below the North Pole.

Capella and Vega.

111. If a line is drawn across the Pole at right angles to a line joining the Great Bear to Cassiopeia, it will pass near the two first-magnitude stars, Capella and Vega, situated 45° and 52° respectively from the pole. These four objects are the most conspicuous in the N. sky and may be said to form a cross, the intersection of the arms of which is the Pole Star.

Arcturus and Orion.

112. If the tail of the Great Bear be continued, it will lead to another first-magnitude star, Arcturus, in 20° N. dec. and 14 h. R.A. If a line be drawn from the pole through Capella it will strike the well-known constellation Orion. The sword of Orion points to the celestial south.

Sirius.

113. Turning now to the stars of the S. hemisphere, about 15° S.W. of Orion is Sirius, the brightest star in the sky.

South Pole.

114. About 36° S. of Sirius is another very bright star, Canopus, and at another distance of 36° is the South Pole. This is not marked by any conspicuous star, but there is a fifth-magnitude star, Sigma Octantis, distant only 47′ from the South Pole.

Southern Cross and South Pole.

115. If a line be drawn between the N. and S. Poles, through Arcturus, it will meet, at about 30° from the South Pole, two bright stars, Alpha and Beta Centauri. These are sometimes known as the Pointers, as they point towards the Southern Cross. This constellation when visible gives us another method of finding the South Pole, as described in the "Manual of Map Reading," as follows :—"Consider the Southern Cross as a kite; prolong the greater axis $4\frac{1}{2}$ times in the direction of the tail, and the point reached will be approximately the South Pole of the heavens."

Zodiac.

116. The ecliptic, *i.e.* the apparent path of the Sun in the sky, is shown in Plates I and II as a dotted line. The constellations along the ecliptic are known as the twelve signs of the Zodiac, and may be remembered by the following rhyme :—

The Ram, the Bull, the Heavenly Twins,
The next the Crab, the Lion shines,
The Virgin and the Scales.
The Scorpion, Archer, and He-goat.
Aquarius and his waterpot,
The Fish with glittering tails.

The Ram (Aries) is marked by two third-magnitude stars, and may be found by taking a line from the Pole Star through the last star of the W of Cassiopeia.

The Bull (Taurus) contains the group of the Pleiades and a bright red star called Aldebaran, found by producing Orion's belt N.E.

The Twins (Gemini) are two bright stars N.W. of Orion.

The Crab (Cancer) is an inconspicuous constellation, but for a remarkable cluster of stars called Praesepe.

The Lion (Leo) is to be found S. of the Great Bear. The preceding stars are shaped like a sickle, and they are followed by three shaped like an isosceles triangle.

The Virgin (Virgo) is shaped like a Y, the brightest star, Spica, being at the base.

The Scales (Libra) contain no conspicuous stars.

The Scorpion (Scorpio) is a very realistic constellation, the principal stars being coiled like a scorpion's tail ready to strike. Antares, the heart, is a brilliant red star.

The Archer (Sagittarius) contains four stars forming a parallelogram; they lie in the brightest part of the Milky Way.

The He-goat (Capricornus), Aquarius and the Fishes (Pisces) contain no stars of importance.

First Point of Aries.

117. Of the two points where the ecliptic cuts the celestial equator, that where the Sun passes into the northern hemisphere is known as the " First Point of Aries " (see Chapter II), and it is from this point that R.A. is measured. It is no longer in the constellation Aries, but in that of Pisces. The expression is, however, retained for convenience. This change of position is due to the movement called the Precession of the Equinoxes, which we need not discuss. The Sun reaches this point on March 21.[1]

Tropics.

118. The ecliptic reaches its greatest northern dec. (23° 27′) in R.A. 6 h. The Sun will be overhead at noon on June 21 [1] at any place in 23° 27′ N. latitude. This date is called the Summer Solstice, and the parallel of latitude of 23° 27′ on

[1] This date and those mentioned in the next few paragraphs may vary by a day, as Leap Year affects the question.

the earth's surface is called the Tropic of Cancer, although the Sun is not in Cancer on the date mentioned. The Winter Solstice occurs on December 22,[1] and the Sun is then in R.A. 18 h. The parallel in the southern hemisphere corresponding to this is called the Tropic of Capricorn.

Aries.

119. The expression seen in some almanacs that the Sun enters Aries on March 21 does not mean that the Sun is actually in that constellation, but that it has passed R.A. 0 h.; for conventional reasons the constellation is regarded as stretching along the ecliptic between 0 h. and 2 h. R.A.

How to find stars visible at a certain time.

120. It is useful to know what stars will be visible on a given date at a given time, and, conversely, to know when to look out for certain stars. A *planisphere* is a useful invention for this purpose. As, however, one would probably not be available on service, and as they are useless outside the latitude for which they are designed, the steps by which we may find what stars are visible may be explained. If a star-chart is available, the process is extremely simple and involves no calculations.

The sun is at R.A. 0 h. on March 21. At noon on this day, therefore, this line will be on the meridian. The following midnight 12 h. R.A. will be on the meridian.

Suppose the observer is in 30° N. latitude. The altitude of the pole will be 30°. A point +60° dec., 0 h. R.A. will be on the horizon due north—this we find to be about the constellation Cassiopeia. A point — 60° dec., 0 h. R.A. will be on the horizon due south—this is within the Southern Cross. Points on the equator, 6 h. and 18 h. R.A., will be due east and west on the horizon. If now we join up these points on a star chart, it is sufficiently accurate to say that all the stars included in this area will be visible. It must be remembered that stars close to the horizon will probably be lost in the haze.

An hour after midnight, March 21–22, 13 h. will be on the meridian; at 0200, 14 h.; at 2300 11 h.; at 2200 10 h., and so on.

[1] This date and those mentioned in the next few paragraphs may vary by a day, as Leap Year affects the question.

A month after March 21 the sun will be in R.A. 2 h.; hence 14 h. will be on the meridian at midnight on April 21–22. Each day makes a difference of just about 4 m. of R.A. That is to say, the sun's dec. on April 22 is 2 h. 4 m.; on April 23, 2 h. 8 m., and so on.

These rules suit any latitude and any longitude. It is seldom necessary to correct for distance from the standard meridian, but summer time must be allowed for. They may be summarized as follows :—

1. Find the Sun's R.A. as follows :—The Sun's R.A. on March 21 is 0. For every month after March 21 add 2 hours and for every day add 4 minutes.

2. To this figure add the time elapsed since noon, and subtract 24 hours if necessary. This will give the R.A. on the meridian.

Example.—What stars will be visible in N. lat. 50° on January 1 at 2030 ?

January 1 is nine months and 10 days from March 21. The sun's R.A. is therefore $2 \times 9 = 18$ h. plus $10 \times 4 = 40$ m., or 18 h. 40 m.

Add 8 h. 30 m. We get 27 h. 10 m.

Subtract 24 h. Result—3 h. 10 m. will be on the meridian.

Referring now to the star charts on Plates I and II, we mark this meridian and its prolongation 15 h. 10 m. On Plate I mark the point where this cuts the dec. + 50°. Mark two points on the equator 21 h. 10 m. and 9 h. 10 m. Join these points. This will give the stars visible in the northern hemisphere, *i.e.* the Great Bear will be visible low down N.W., and the Lion will be just setting. The zenith will be dec. + 40°, near the Pleiades.

In Plate II mark the two points on the equator just mentioned, and join them to a point 3 h. 10 m. R.A. and — 50° dec. The stars north of this line will be visible. They include Sirius, Orion, etc.

When to look for certain stars.

121. Conversely, it is often useful to know when to look out for a certain star or constellation. The reasoning is similar to that given above, and will be most conveniently given as an example.

Example.—In lat. 20° N., when may the Southern Cross be looked for ?

The Southern Cross is in — 60° dec., 12 h. 20 m. R.A. Therefore it will never be above 10° altitude at this latitude. It will be on the meridian and consequently best visible at midnight, when the sun's R.A. is 0h. 20 m., *i.e.*, 5 days after March 21, or March 26; at 2200 on April 26; at 2000 on May 26, and so on.

Stars in charts.

122. In looking for stars from a chart, a word of caution should be added. Setting stars lose their brightness rapidly and become invisible before they reach the horizon. The converse happens when stars are rising. If the chart shows a bright star which calculations show will be near the horizon, one must expect to see it very much dimmed, if at all.

At Full Moon stars of about the fourth and lower magnitudes are invisible.

A popular error.

123. Here it may be mentioned that there is no foundation in fact for the common belief that stars are visible in daytime when looking up from the bottom of a pit. The belief no doubt grew from the fact that a narrow opening like a shaft mouth shows like a single star-like object when seen from a great depth. It may be added that in most latitudes not more than two lucid stars at the most would appear to cross such an opening during the whole 24 hours, and these would traverse it in a few moments.

Star atlases.

124. For those who desire a better acquaintance with the stars, there are many star atlases, both good and cheap, obtainable in the market.

CHAPTER X.

DIRECTION BY THE STARS

Guiding a column by the stars.

125. PROBABLY the greatest use to which astronomy can be put for military purposes is that of guiding a column by the stars. It is a comparatively easy matter to anyone who is acquainted with the movements of the stars.

Comparative advantages of using stars and compass.

126. With care, the stars give a more accurate method of alignment than the compass; yet the latter must never be neglected, since clouds may render the former method useless. Apart from this, the advantages of using stars instead of a compass can be summarized as follows :—

1. A star is visible to everyone in the column; a compass can be seen effectively only by the holder.
2. With a compass it is necessary to halt frequently and allow the needle to come to rest; the use of the stars therefore makes for greater pace.
3. A compass is affected by the presence of iron in the ground, in accoutrements, etc.

A method of marching by the stars not involving the use of charts, given the bearing on which to march, is as follows :—

Northern hemisphere.

127. If it is desired to march upon a given bearing,[1] say 60°, describe an angle [2] of 60° on a piece of white cardboard in lines sufficiently broad to be easily distinguishable in the dark. Lines $\frac{1}{8}$ of an inch broad will usually be easily seen on a starlight night. They should be not less than about 9 inches long. Direct the left-hand line on the pole, which is found as directed in the last chapter. The other line gives the direction

[1] Needless to repeat, the expression "bearing" means true and not magnetic bearing.

[2] A method of describing angles without a protractor is given in Chapter II.

in which it is required to march. Choose a star in this direction and march on it. If the bearing is greater than 180°, say 320°, describe an angle of 360° − 320° = 40°, and, directing the right-hand line on the pole, choose a star in the direction indicated by the left-hand line and march on it.

Two points must be noted. One is that, if the pole is high in the sky, it is convenient to lay on a point on the horizon or a star vertically under the pole. This is easily found by holding a pencil or straight stick vertically at arm's length so that the pole is near the top. The other point is that one must be careful to lay on the pole, and not on the Pole Star, though if Zeta Ursae Majoris is above or below the Pole Star, the difference between the two positions may be neglected (see para. 109) or the difference may be allowed for in describing the angle, but this is open to the objection that the position of the Pole Star varies slightly in the course of the night.

Southern hemisphere.

128. If the bearing on which it is desired to march is less than 180°, say 70°, describe an angle of 180° − 70° = 110°, direct the right-hand line on the S. Pole, and march on the left-hand line. If the bearing is greater than 180°, subtract 180° from it, describe the angle and direct the left-hand line on the S. Pole, and march on the right-hand line.

The same remark as to selecting a point below the S. Pole to orient one of the lines applies as in the case of the N. hemisphere. But as the S. Pole star, Sigma Octantis, is only 47′ from the pole it is hardly necessary to allow for this small difference.

Convenient stars for the purpose.

129. There will generally be several stars close enough at one time to the required bearing to be used as guides. The choice of a particular one is important. The "Manual of Map Reading" states that "the most convenient stars to select for marching on are those which happen at the time to have an altitude of from 15° to 30°; stars below 15° may become lost in haze, whilst for those above 30°, the head has to be inconveniently raised." This restricts the possible selection, though the lower limit may be safely reduced to 5°

in clear skies. But of stars within these limits, those on a level with the elevated poles should be chosen in preference to others, as they move less in azimuth (*i.e.* to a flank) in the same time. The motion to a flank is greatest in stars on the celestial equator on or near the meridian, and least in stars near the pole or at the same altitude as the pole. The most unfavourable direction to march is therefore due S. in a high N. latitude, or due N. in a high S. latitude. But in all cases constant setting of the angle on the cardboard with a fresh star will reduce the possible error to a very small amount.

If the course of the march entails a change of direction, another angle of the required dimensions should be prepared beforehand. The greater the movement of the guiding star in azimuth, the more often will it be necessary to halt and choose another star. In the most unfavourable cases a star may move a degree in azimuth in four minutes, and, as a degree may be taken as the greatest permissible error, in such cases it will be necessary to halt and re-direct one's course every four minutes. But in most cases, especially if a guiding star is carefully chosen, such frequent halts are not necessary; and in low latitudes the same star may be used for an hour or more. An error of one degree will mean a deviation of 1 yard in 57, or 31 yards in a mile. As greater accuracy is seldom necessary, such an error is not of importance.

The history of the Great War includes many instances of escapes, where the escaping party found their way to a great extent by means of their knowledge of the motions of the stars. A party of 8 officers, whose adventures in escaping from Yozgad in Asia Minor are ably recorded in "450 Miles to Freedom," provided themselves with star charts showing the bearing of the principal stars between 10° and 60° in altitude and between 90° and 360° in bearing for the months of August and September. These charts proved of the greatest use.

Variation of the compass.

130. To find the variation of a compass it is necessary, in the N. hemisphere, to align the compass on the Pole Star, when Zeta Ursae Majoris is above or below the Pole Star. The

reading will give the variation. If Zeta Ursae is due E. or W. of the Pole Star, 1° subtracted from or added to the bearing of the latter will give the correct variation.

In the S. hemisphere, the bearing of Sigma Octantis less 180° will give the magnetic variation. If the amount is positive, the variation is W., and if negative E.

Example.—The compass bearing of Sigma Octantis is 167°. What is the variation of the compass?

167° − 180° = − 13°. The variation is therefore 13° E.

CHAPTER XI

TIME BY THE STARS

131. THE advantages of some rough-and-ready method of telling the time by the stars are obvious; on service, as well as on manœuvres and in every-day life, one may be without a watch at night, or it may be dangerous or impossible to strike or show a light to look at one. The relief of sentries, the time of any occurrence of importance witnessed by a patrol, the necessities of a march of concentration or a time march are some of these occasions. Advantages of method.

We have already seen that stars appear to describe circles round the elevated pole (Chapter I), and that they complete this circle in a day, less about 4 minutes (Chapter IX). If therefore we know the position of a star with respect to the elevated pole at any given date and time, we can on any date calculate the time from the position of that star. An essential part of such calculation must be that it must be as easy as possible and require none but the simplest mental arithmetic. Any method which requires paper and pencil would, of course, be useless. The methods given below involve a knowledge of the positions of only a few stars, and a calculation which can be done in one's head in a few seconds.

132. The stars used are those with which almost everybody is acquainted. They are the Pole Star and the two stars in the constellation of the Great Bear, called "The Pointers," or to speak more accurately, that star of the Pointers nearer to the Pole Star (Alpha Ursae Majoris, or Dubhe), henceforth, for simplicity, called A. Northern[1] hemisphere.

Take the Pole Star as the centre of a clock, the circle described

[1] I am indebted to the late Major-General Rice, Bengal Staff Corps, for this method. It was published in the *R.E. Journal* in April 1905.

by A in its revolutions as the face of the clock, and a line drawn from the Pole Star to A as the hour-hand. Thus, in fig. 24, P is the Pole Star; A the Pointer; UWLE the face of the clock; and the dotted line PA the hour-hand. For convenience and to avoid the use of technical terms, we will take U as the point directly above the Pole Star, L the point directly below it, W a point directly west, and E a point directly east of it. If the Pole Star and pole coincided, U and L would be on the meridian; but as there is a distance of about 1° 7′ between them, they are only on the meridian when

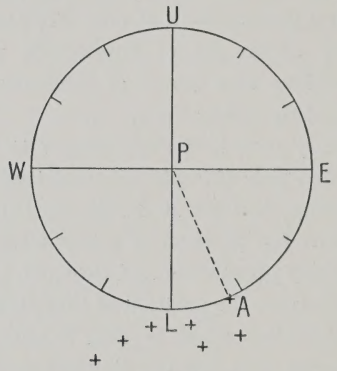


Fig. 24.

P is on the meridian. Speaking roughly, A revolves round the Pole Star once in 24 hours; it therefore reaches W 6 hours, L 12 hours, and E 18 hours respectively after it leaves U. If therefore it is known that A is at U at any given hour, say at 1700, it is at once apparent that it reaches W at 2300, L at 0500, and E at 1100, though, of course, for part of this time (during the day) it would not be visible.

Knowing therefore that A travels from U to W in six hours, it is easy to calculate that it will travel half-way to it in three hours, one-third of the way in two hours, one-sixth of the way in one hour, and so on. So that, if we know that A was at U at any given time, say 1700, we have only to estimate what

portion of the distance between U and W it has travelled to be able to tell what the time is, and in the same way for other quarters of the clock.

We know also, that, roughly speaking, A will arrive at U four minutes earlier every day; this interval is equivalent to two hours in a month or to one day in a year.

Now it is sufficiently accurate to say that A is at U at 1700 on June 21 [1] every year—a date easy to remember as it is the longest day in the year—the Summer Solstice. A is therefore at U at 1500 on July 21, at 1300 on August 21, at 1100 on September 21, and so on.

Suppose, for instance, that on the night of July 21 A has

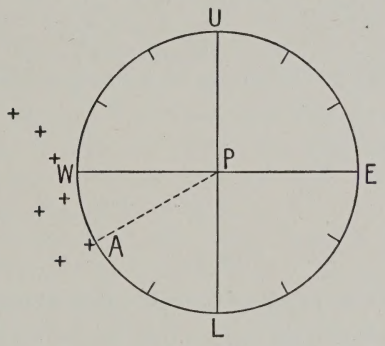


FIG. 25.

reached the point shown in fig. 25, which we estimate at one-third of the way from W to L. Taking as the basis that A was at U at 1700 on June 21, and remembering that it reaches U two hours earlier for each month after that date, we find that A must have been at U on that day (July 21) at 1500; consequently, it would reach W six hours later, or at 2100, and that as A is one-third of the way from W to L (two hours' journey) the time must be just 2300.

[1] A more correct date would be June 23; on June 21 A is at U about 1706; but June 21 (the Summer Solstice) is taken as being an easier date to remember. The difference of six minutes is usually lost in the errors of observation.

Again, suppose that on December 21 we find the stars as in fig. 26, and estimate A to be five-ninths of the way between E and U, if we deduct $\frac{4}{9} \times 6$ hours, or 2 hours 40 minutes, from 0500, it will give us 0220, which is the right time.

So far we have only dealt with instances of observations taken exactly one or more months after June 21, but the calculations in which fractions occur are equally simple, since one day makes a difference of four minutes. Thus we have only to subtract four minutes for each day that has elapsed since

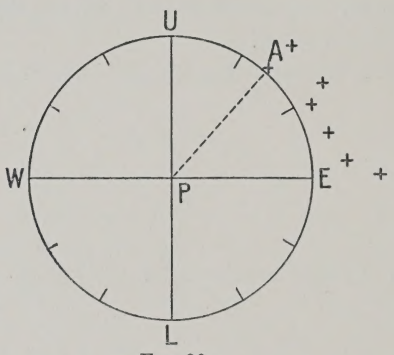


FIG. 26.

the first of any month to give us the exact time at which A was at U.

Example.—On June 30 A will be at U thirty-six minutes earlier than on June 21, *i.e.* at 1624.

Suppose, for instance, that on Jan. 18 we find A in the position indicated in fig. 26, *i.e.*, five-ninths of the way from E to U. Starting as usual from the datum of A being at U at 1700 on June 21, we find that on January 21 A will be at U at 0300, and as the 18th is three days short of this, it would be at U twelve minutes later, or at 0312. A will still take $\frac{4}{9} \times 6$ hours $= 2$ hours 20 minutes to reach U, and hence we must deduct this from 0312, and so find the time to be 0052.

Practical details.

133. In practice, the chief difficulty is to tell with sufficient accuracy, without instruments, what position A actually occupies on the face of the clock.

The best method is to hold a cane or straight stick perpendicularly, so that the side of the cane nearest to A just

appears to cut the Pole Star. As this hangs down perpendicularly, it gives us U and L. Then hold a smaller stick, such as a pencil, at right angles to the cane, so as to be able just to see the Pole Star in the angle formed by the cane and the pencil. This enables one to estimate with fair accuracy the position which A occupies in the quarter of the circle in which it happens to be.

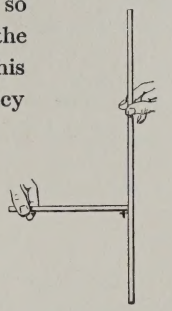


Fig. 27.

In high northern latitudes, where the Pole Star is at a considerable altitude, it is often advisable to hold the cane horizontally and the pencil perpendicular to it.

For very rough guessing, one hand held up perpendicularly and the other held at right angles to it, or the straight side of a house or trunk of a tree may be used for finding the positions of U and L.

To recapitulate briefly the rules given above :—

1. A is at U at 1700 on June 21.
2. Each month after this date A reaches U two hours earlier, and each fraction of a month four minutes earlier for each day of that fraction.
3. In every twenty-four hours A travels round the circle, traversing each quarter of it in six hours, and each fraction of a quarter in a like fraction of that time.

Rules for low N. latitudes

134. Near the equator it may happen that A is not visible all night, as it will at one time of the year rise and set like most of the other stars. When this is the case we must use another star. We saw in para. 110 that there is a constellation called Cassiopeia nearly opposite to the Great Bear, on the other side of the Pole Star, from which it is at about the same distance (see Plate I). It contains five bright stars in positions something like the five points of a W. The middle one of these (Gamma Cassiopeiae) is the star to use.[1]

[1] Henceforward called B.

It is sufficiently accurate to say that B is ten hours in advance of A; therefore all that is necessary when using the star is to calculate the time by it exactly as if it were A, and from the time when found to deduct ten hours.

Example.—On August 23, A not being visible, B is in the position shown in fig. 28, estimated at half of the way from U to E.

By rules 1 and 2, we find that on that day A was at U at 1252; if therefore it were where B is, the time by rule 3 would be three hours short of 1252, or 0952; from this deduct the ten hours difference between A and B, and we find the time to be 2352.

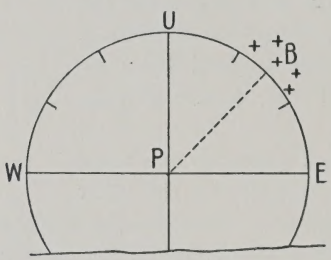


FIG. 28.

Hence, for low northern latitudes, it becomes necessary to add a fourth rule :—

4. When A is not visible, observe B, as if it were A and deduct ten hours from the time found. When A and B are both visible, the time found by B may be used as a check on that found by using A.

Difference for local time.

135. These rules do not, of course, allow for the difference between local and mean time owing to the distance of a place from the standard meridian (see Chapter VI). On the meridian itself no allowance need be made, nor is it of much importance if we do not allow for a difference of 2° or less in longitude between a place and the meridian from which it takes its time. In other cases a calculation, fortunately simple, must be made. For every degree E. or W. of the time-giving meridian, four minutes must be subtracted from or added to the time found by observing the stars.

Example.—At Glasgow, long. 4° 15′ W., 17 minutes must be added to the observed time.

Delhi, long. 77° E., is 5½° west of the standard meridian for India; 22 minutes must therefore be added to the observed time.

We must therefore add a fifth rule to these given above.

5. When standard time is in use $\frac{\text{add}}{\text{subtract}}$ four minutes for every degree of longitude $\frac{\text{W}}{\text{E}}$ of the time-giving meridian.

Also, where applicable,

6. When summer-time is in force, add one hour.

Southern hemisphere.

136. The case of the southern hemisphere is more difficult than that of the northern, since the South Pole Star, Sigma Octantis, is a faint star at the best of times and quite invisible to the naked eye at or near Full Moon. As we have to use it as the centre of our clock, it will often be necessary to estimate its position from that of the surrounding brighter stars, the Southern Cross, for example (see para. 115).

As the hour-hand, we use the line joining the South Pole Star to Alpha Centauri, one of the brightest stars in the sky (see para. 115).

It is very nearly correct to say that this star, which we will call C for short, is vertically above the South Pole Star at midnight on April 30–May 1. The process of calculation is exactly the same as with the stars we selected for use in the northern hemisphere, the only difference being that in the southern hemisphere the stars appear to move in an opposite direction to those in the northern hemisphere, *i.e.* clock-wise instead of against the clock; that is to say, that E will be to the left and W to the right of the sidereal clock in the southern hemisphere.

Example.—On March 8 we find C in the position shown in fig. 29. We estimate this to be one-quarter of the way from U to W. What is the time?

C is at U at midnight on April 30–May 1. It will therefore be there 2 hours later, or at 0200 on April 1, and 23 × 4 minutes after this on March 8. That is to say, C is at U at 0332 on March 8. It will take a

quarter of six hours, or one hour thirty minutes, more to reach its position as indicated on fig. 29. The time is therefore 0502.

The rules for the southern hemisphere may therefore be given briefly as follows :—

1. C is at U at midnight on April 30–May 1.
2. For every month after this date, C is at U two hours earlier, and for every fraction of a month four minutes earlier for every day of that fraction.
3. In every twenty-four hours C moves once round the circle in the same direction as that of the hands of a watch, traversing each quarter of the circle in six hours and each fraction of a quarter in a like fraction of that time.

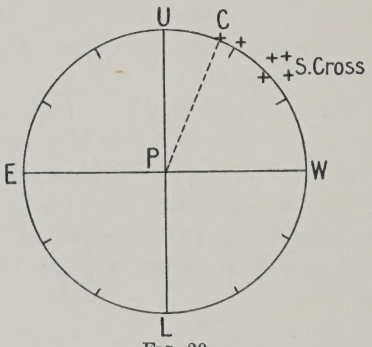


FIG. 29.

If C is not visible, another star, called Achernar (Alpha Eridani) may be used. It is almost exactly eleven hours behind C, its position with regard to which can be seen in Plate II. Unfortunately this star, though a first-magnitude star, is very hard to recognize, as it is surrounded by very insignificant stars. It very nearly bisects a line joining the two bright stars Canopus and Fomalhaut. We will call Achernar D for short. Thus, if we wish to find the time by means of D, all we have to do is to observe D as if it were C and add eleven hours.

Example.—On September 22 we find D in the position shown in fig 30. This we estimate as half-way between E and U.

If C were in that position, we would calculate as follows :

C is at U at midnight on April 30–May 1. C will therefore be at U eight hours earlier, or at 1600 on September 1, and $4 \times 22 =$ one hour and twenty-eight minutes earlier on September 22, *i.e.* at 1432. It will take three hours to reach the position shown in fig. 30; hence we get 1732. Since we are observing D and not C, we must add eleven hours, and we therefore find the time to be 0432.

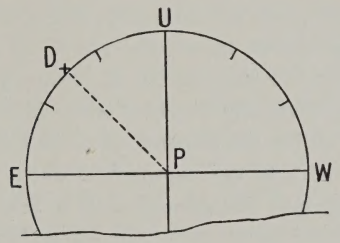


Fig. 30.

We must therefore add a fourth rule :—

4. If C is not visible, observe D as if it were C, and add eleven hours to the result.

Rule 5 is the same as in the northern hemisphere :—

When standard time is in use $\frac{\text{add}}{\text{subtract}}$ four minutes for every degree of longitude $\frac{\text{W}}{\text{E}}$ of the time-giving meridian.

So also is rule 6 when applicable :—

When summer time is in force add one hour.

CHAPTER XII

THE PLANETS

Military uses of planets.

137. We have enumerated the principal planets in Chapter I. For military purposes their only use is as guides in night marching. They are more useful than stars for this purpose, since they are generally brighter and shine more steadily, and are often visible when many stars are lost to sight owing to haze, moonlight, or the approach of dawn

Mercury.

138. Mercury may be dismissed in a few words, as it is visible only occasionally, and then for a very short time in twilight after sunset and before sunrise, when it would be quite useless as a guide for marching.

Recognition of planets.

139. We now turn to the properties common to the remaining four planets visible to the naked eye—Venus, Mars, Jupiter and Saturn. It is commonly said that planets may be recognized by the fact that they do not twinkle. But in certain conditions of the atmosphere they do twinkle; while at other times even the stars shine with hardly a perceptible twinkle. Nor is brightness a criterion, for Saturn and Mars seldom appear brighter than the first magnitude, while Venus and Jupiter, though often the brightest objects in the sky, are very inconspicuous at other times. The criterion of a planet is its motion with regard to the fixed stars; it was this peculiarity that gave them their name. Careful observation extending over twenty-four hours will usually show an appreciable change of position in the case of Venus and Mars, while a longer interval is required for Jupiter and Saturn.

Positions of planets in the sky.

140. The planets are always to be found within a few degrees of the ecliptic. The positions of the four principal planets are given in most almanacs. It is therefore quite simple to find them from the rules in Chapter III.

141. Venus appears alternately as a morning and evening star. Beginning as a faint object in the eastern sky, visible before sunrise, she increases in lustre very rapidly, and remains visible for about eight months; then for three or four months she is invisible, reappearing again as an evening star. Thus she remains for another eight months, first increasing slowly in brightness, and then rapidly losing her brightness, until, for another period of a few days, she is invisible. The whole cycle, or " epoch " as it is termed, occupies a year and nine months. Venus is never distant more than 48° from the Sun, and therefore is never visible except in the west after sunset or in the east before sunrise. This, coupled with the fact that she nearly always surpasses Jupiter in brightness, enables Venus to be recognized very easily. Although her motion with respect to the stars is often noticeable to the eye in twenty-four hours, the difference of position is not of sufficient moment to affect the use of this planet as a point for marching on. Venus.

142. Mars, the next planet in order from the Earth, is usually as bright as a first-magnitude star; his red colour has changed appreciably of late years and he usually shines with a dull yellow colour.[1] Mars takes about two years to perform the circuit of the heavens, his motion being nearly steady except when the Sun, Earth and Mars are in a line, when he " retrogrades " (that is to say halts, moves backward, halts) and then resumes his forward movement. This retrogression is an effect produced by the earth's greater velocity causing it to " catch up " Mars. The same effect is produced in the case of all the superior planets. During about eight months of his epoch Mars is invisible to the naked eye, as the Sun is then between Mars and the Earth. The retrogression can be seen in fig. 31, which shows an actual portion of the track of Mars in 1922. Mars.

143. Jupiter, the brightest of the planets except Venus, is visible for about eight months every year. Beginning from Jupiter.

[1] This change is supposed to be due to the presence of dust clouds in the Martian atmosphere.

the time when he is just visible before dawn, he rises earlier with respect to the Sun until he finally ceases to be visible after appearing for a very short time after sunset. Like Mars he retrogrades once in each apparition, but the amplitude of his retrogression is much less. His epoch is thirteen months. He moves slowly, passing through the whole zodiac in thirteen years.

Saturn.

144. Saturn appears as a dull yellow object of about the first magnitude. He is at present (1924) in Virgo. His epoch is twelve and a half months, during which he retrogrades,

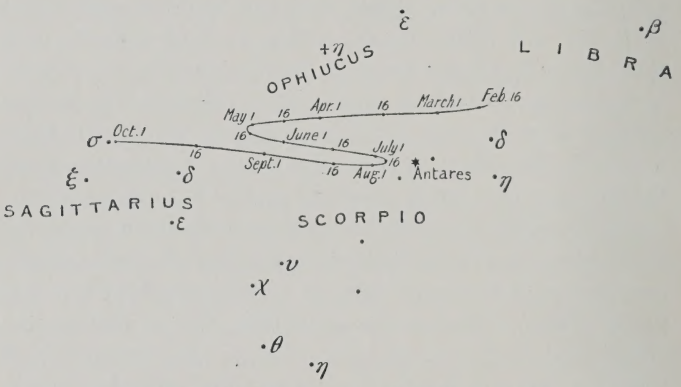


FIG. 31. Part of apparent path of Mars, 1922.

for a shorter distance than Jupiter. His motion is extremely slow; he takes twenty-nine years to complete the circuit of the sky.

Zodiacal Light.

145. Mention should be made of the Zodiacal Light, a phenomenon to be seen after sunset or before sunrise. It may be described as diffused light, usually equal to the Milky Way in intensity, stretching along the ecliptic for 90° or more from the Sun. Except as a forerunner of dawn (it is often called False Dawn) and a rough guide to the east, it is not of much use in military operations.

Shooting stars.

146. Meteors, meteorites or shooting stars do not in the least resemble the fixed stars. They are particles of matter

in space, which, striking the earth's atmosphere with great velocity, incandesce at once. Their appearance is in no way connected with the weather, as was once generally thought. Occasionally a meteorite strikes the earth. One of the most remarkable struck a stack of chopped straw in the Supply Depot at Quetta in January 1923. The stack was set on fire and destroyed.

Comets.

147. Comets visible to the naked eye are rare visitors. They consist of a nucleus, generally supposed to be an aggregation of meteorites. As the comet approaches the Sun, particles of the nucleus are driven away from the Sun by some repulsive force—probably light-pressure—and form the enormous tails which we associate with the term comet.

A large comet appeared in 1882. It was first detected as a very small object by the officer who directed the night march on the Tell-el-Kebir position during the Egyptian campaign.

APPENDIX I

Table of Natural Tangents

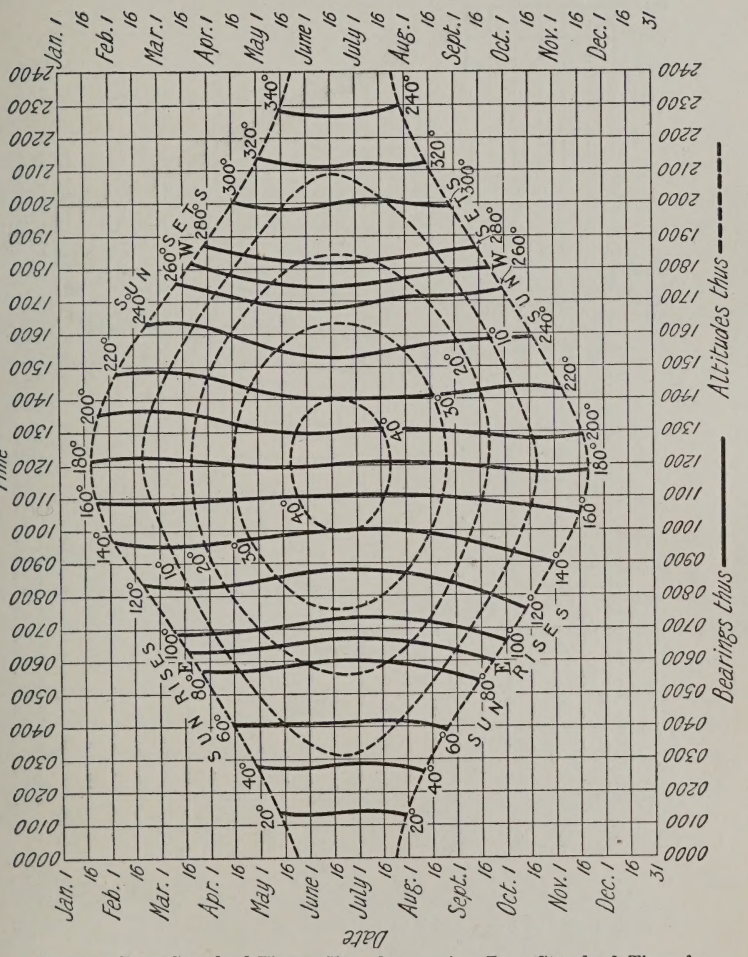
Angle.	Tangent.	Angle.	Tangent.	Angle.	Tangent.
1′	·00029	27°	·510	59°	1·66
10′	·00291	28	·531	60	1·73
20′	·00582	29	·554	61	1·80
30′	·00873	30	·577	62	1·88
40′	·01164	31	·601	63	1·96
50′	·01455	32	·625	64	2·05
1°	·017	33	·649	65	2·14
2	·035	34	·675	66	2·25
3	·052	35	·700	67	2·36
4	·070	36	·727	68	2·48
5	·087	37	·754	69	2·61
6	·105	38	·781	70	2·75
7	·123	39	·810	71	2·90
8	·141	40	·839	72	3·07
9	·158	41	·869	73	3·27
10	·177	42	·900	74	3·49
11	·194	43	·933	75	3·73
12	·213	44	·966	76	4·01
13	·231	45	1·000	77	4·33
14	·249	46	1·035	78	4·70
15	·268	47	1·072	79	5·14
16	·287	48	1·111	80	5·67
17	·306	49	1·150	81	6·31
18	·325	50	1·192	82	7·12
19	·344	51	1·235	83	8·14
20	·364	52	1·280	84	9·51
21	·384	53	1·327	85	11·43
22	·404	54	1·376	86	14·30
23	·424	55	1·428	87	19·08
24	·445	56	1·483	88	28·64
25	·466	57	1·540	89	57·29
26	·488	58	1·600	90	Infinity.

APPENDIX II

(Referred to in paragraphs 43 and 46)

SUN BEARING AND ALTITUDE DIAGRAM.

LAT. 70° N.

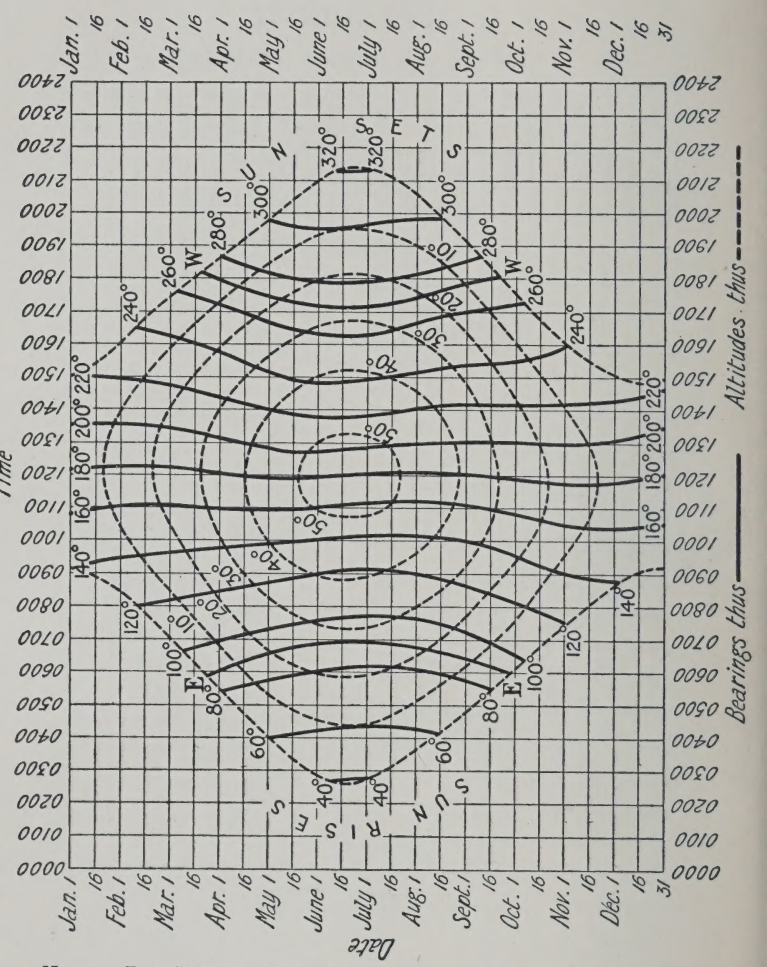


NOTES.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

Summer Time. When Summer Time is in force, add 1 hour.

SUN BEARING AND ALTITUDE DIAGRAM.

LAT. 60° N.

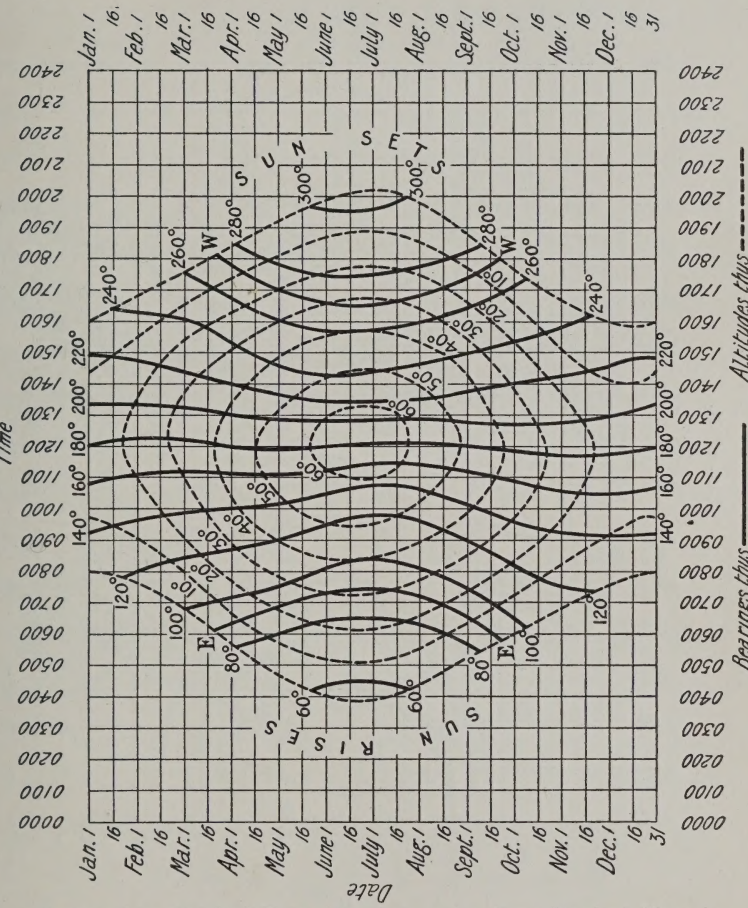


NOTES.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{\text{W}}{\text{E}}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

Summer Time. When Summer Time is in force, add 1 hour.

SUN BEARING AND ALTITUDE DIAGRAM.

LAT. 50° N.

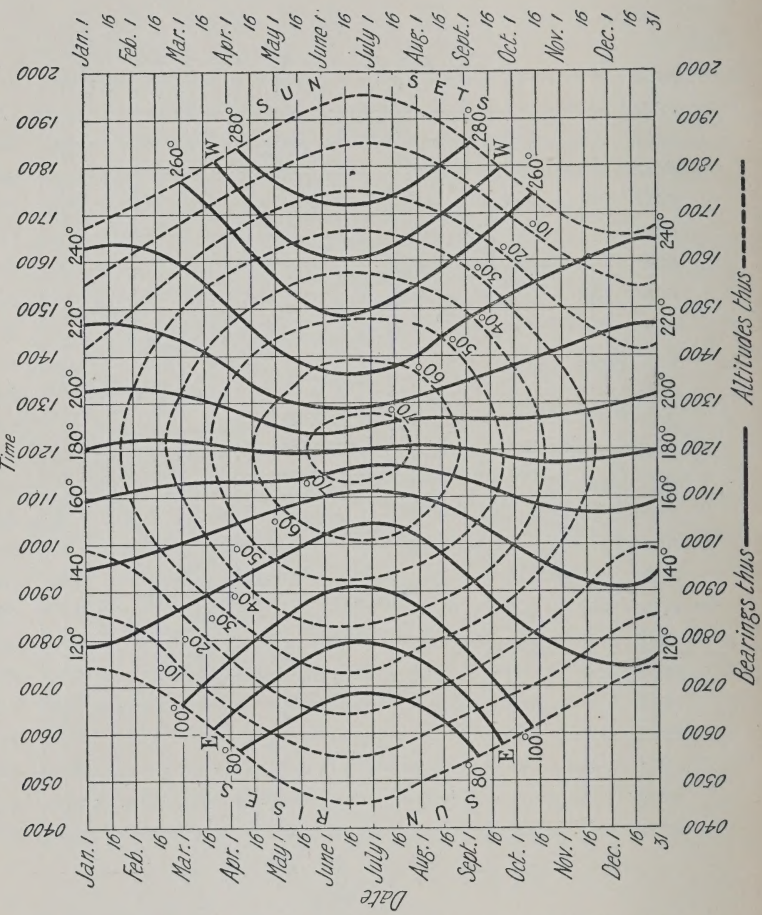


NOTES.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

Summer Time. When Summer Time is in force, add 1 hour.

SUN BEARING AND ALTITUDE DIAGRAM.

LAT. 40° N.

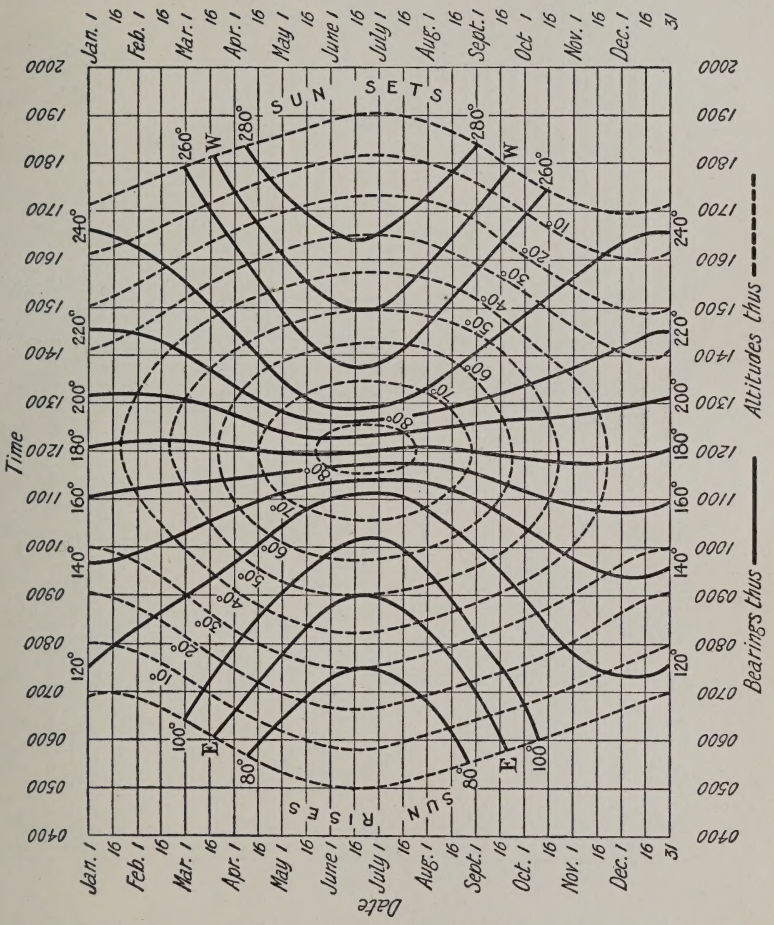


NOTES.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

Summer Time. When Summer Time is in force, add 1 hour.

SUN BEARING AND ALTITUDE DIAGRAM.

LAT. 30° N.

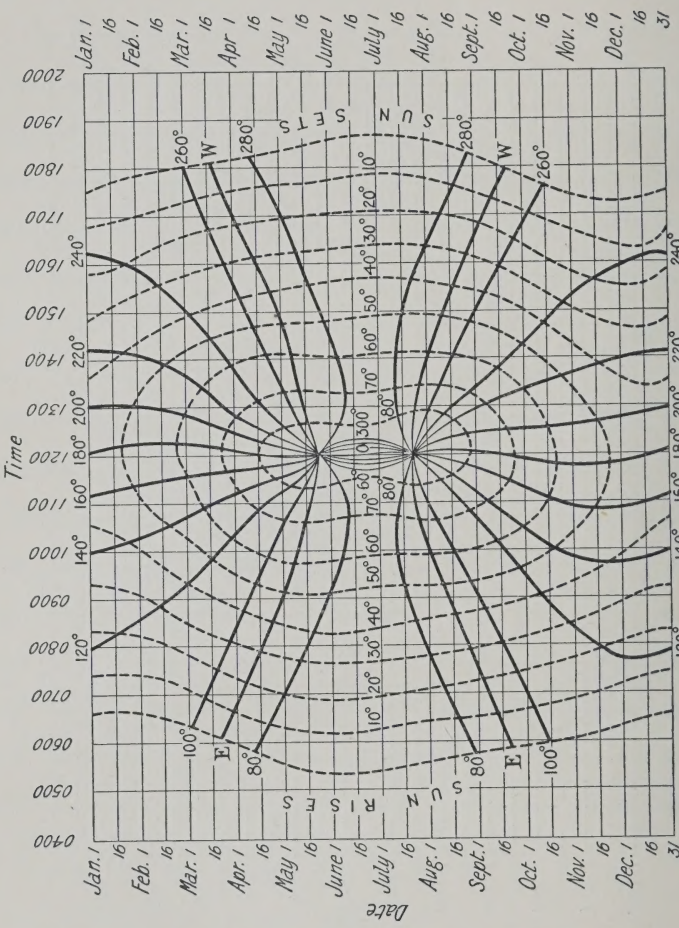


NOTES.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

Summer Time. When Summer Time is in force, add 1 hour.

SUN BEARING AND ALTITUDE DIAGRAM.

LAT. 20° N.

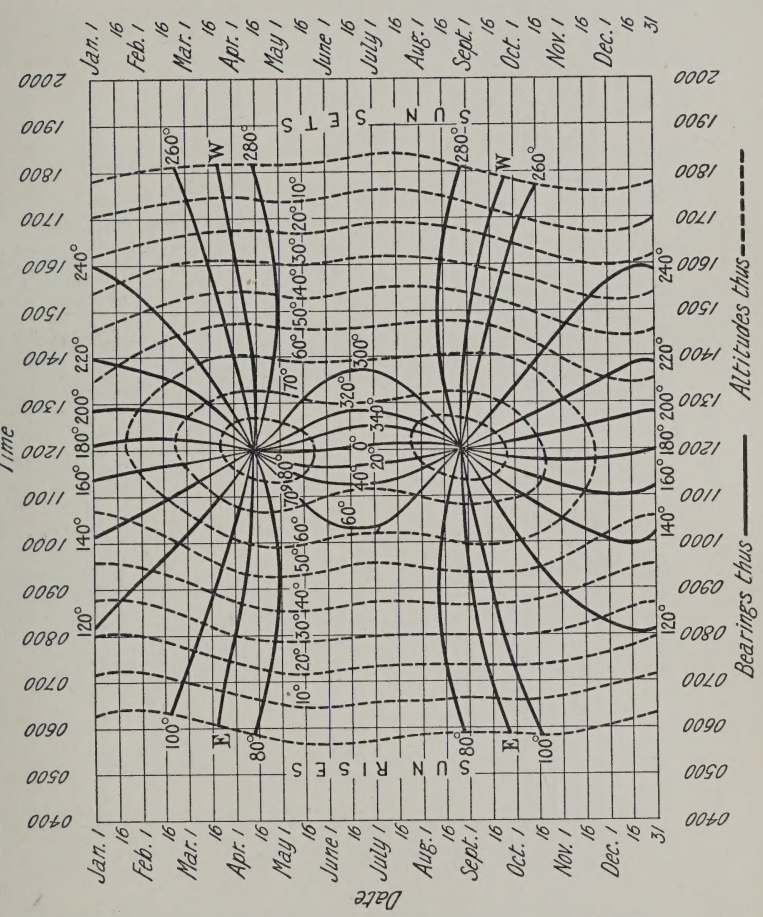


NOTES.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{\text{W}}{\text{E}}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

Summer Time. When Summer Time is in force, add 1 hour.

SUN BEARING AND ALTITUDE DIAGRAM.

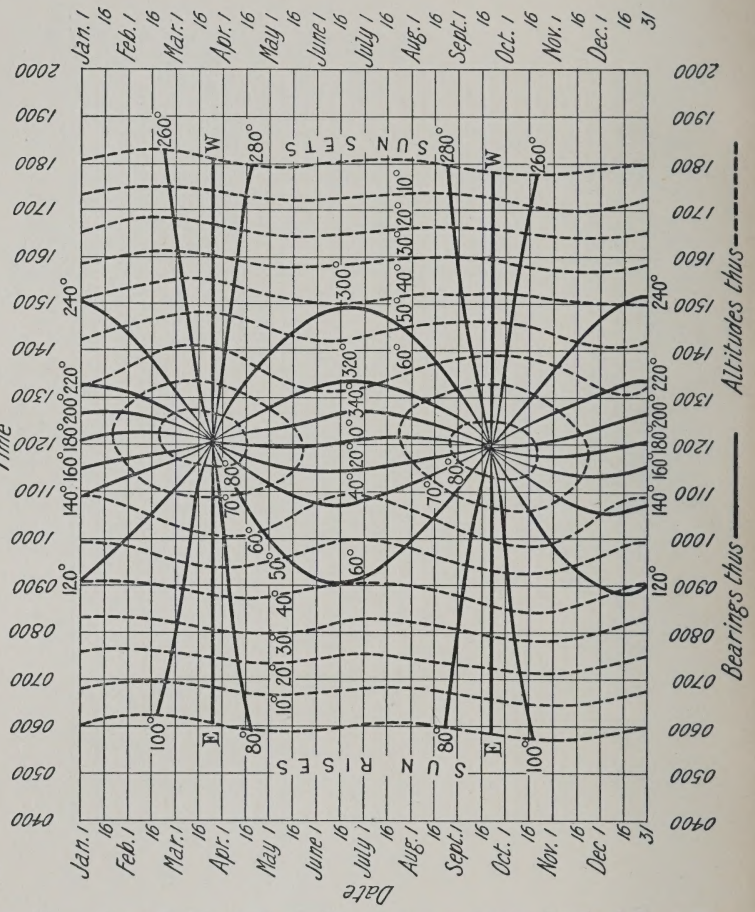
LAT. 10° N.



NOTE.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

SUN BEARING AND ALTITUDE DIAGRAM.

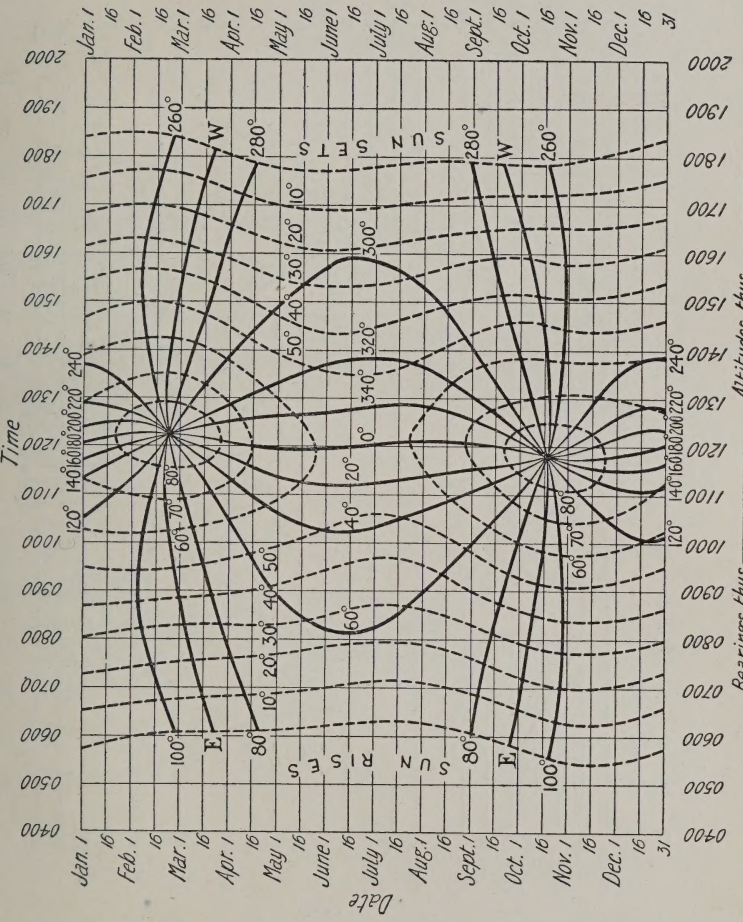
EQUATOR



NOTE.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

SUN BEARING AND ALTITUDE DIAGRAM.

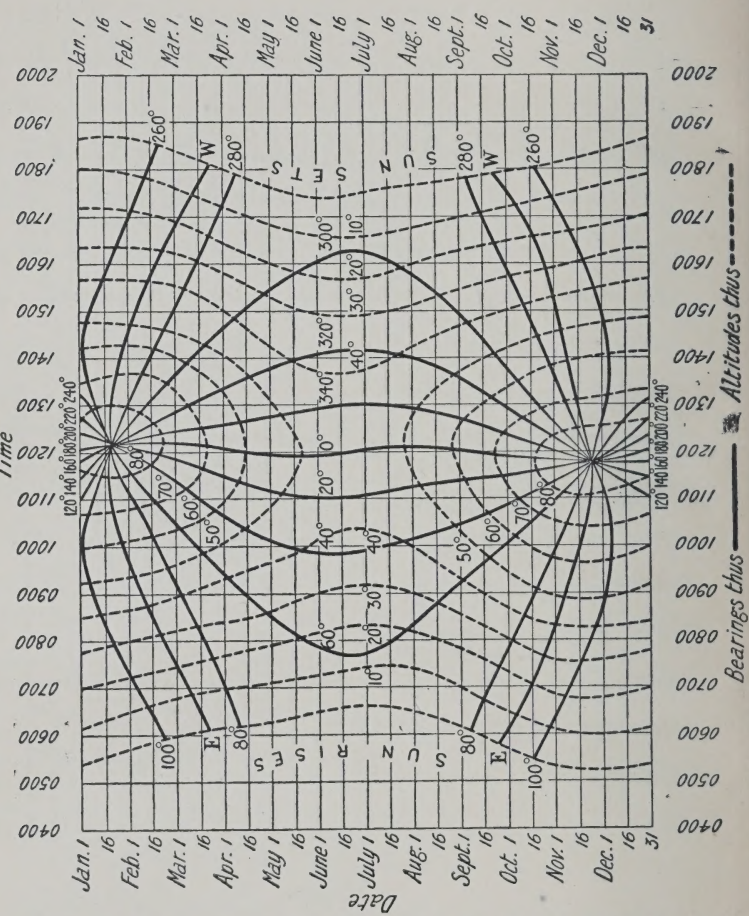
LAT. 10° S.



NOTE.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

SUN BEARING AND ALTITUDE DIAGRAM.

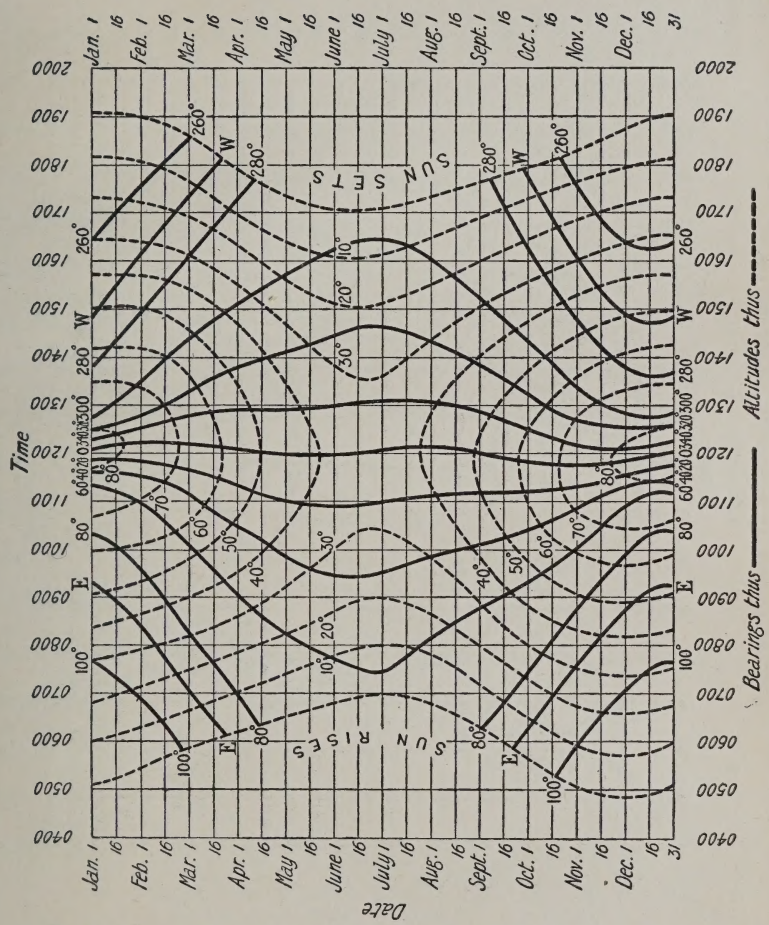
LAT. 20° S.



NOTE.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

SUN BEARING AND ALTITUDE DIAGRAM.

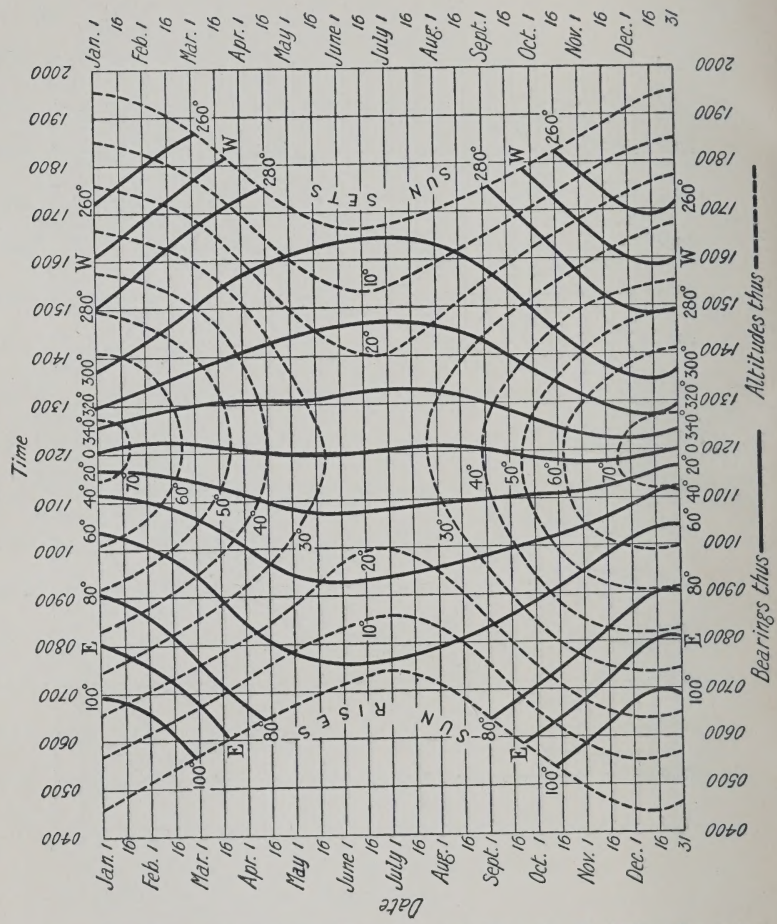
LAT. 30° S.



NOTE.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

SUN BEARING AND ALTITUDE DIAGRAM.

LAT. 40° S.



NOTE.—Zone Standard Time. For places using Zone Standard Time, for each degree of longitude $\frac{W}{E}$ of the standard meridian, $\frac{\text{add}}{\text{subtract}}$ 4 minutes.

APPENDIX III

Calendar from 1924 to 1930

Year.	Jan. 1.	Feb. 1.	Mar. 1.	Apl. 1.	May 1.	Jun. 1.	Jul. 1.	Aug. 1.	Sep. 1.	Oct. 1.	Nov. 1.	Dec. 1.
1924	Tu.	Fr.	Sa.	Tu.	Th.	Sun.	Tu.	Fr.	Mo.	We.	Sa.	Mo.
1925	Th.	Sun.	Sun.	We.	Fr.	Mo.	We.	Sa.	Tu.	Th.	Sun.	Tu.
1926	Fr.	Mo.	Mo.	Th.	Sa.	Tu.	Th.	Sun.	We.	Fr.	Mo.	We.
1927	Sa.	Tu.	Tu.	Fr.	Sun.	We.	Fr.	Mo.	Th.	Sa.	Tu.	Th.
1928	Sun.	We.	Th.	Sun.	Tu.	Fr.	Sun.	We.	Sa.	Mo.	Th.	Sa.
1929	Tu.	Fr.	Fr.	Mo.	We.	Sa.	Mo.	Th.	Sun.	Tu.	Fr.	Sun.
1930	We.	Sa.	Sa.	Tu.	Th.	Sun.	Tu.	Fr.	Mo.	We.	Sa.	Mo.

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PLATE I.

PRINCIPAL STARS IN THE N. HEMISPHERE.

PLATE II.

PRINCIPAL STARS IN THE S. HEMISPHERE.

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